BIOLOGICAL ESCAPEMENT GOALS
FOR ANDREAFSKY RIVER CHUM SALMON

By

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EXECUTIVE SUMMARY

Available information was assembled concerning estimated escapements, harvests and age compositions of summer chum salmon *Oncorhynchus keta* returning to the Andreafsky River, a tributary system to the Yukon River drainage in Alaska. The Andreafsky River joins the Yukon River 104 miles upstream of the mouth of the Yukon River entering about one-third of the way into fishing District 2. The East and West forks of the Andreafsky River support the largest summer chum salmon spawning population in the lower portion of the Yukon drainage. Because of their spawning location, these summer chum salmon are likely exploited less than other summer chum salmon stocks that migrate farther up the Yukon River. This report was written to estimate the escapement levels expected to produce maximum sustained yield fisheries and to make recommendations concerning biological escapement goals.

Total enumeration estimates for the spawning stock of summer chum salmon in the East Fork of the Andreafsky River are available for the years 1981-1984 based upon side-scan sonar methodology, from 1986-1988 from tower assisted counting methodologies, and from 1994-2000 with weir assisted counting methodologies. Additionally, aerial surveys of spawning summer chum salmon in the East Fork of the Andreafsky River are available for most years since 1972. During the 14 years that total escapements were enumerated, aerial surveys in three of those years occurred between the dates of July 14-26 and those surveys were rated as "good" or "fair" by the aerial survey observers. Aerial surveys of the spawning populations of summer chum salmon in the Andreafsky River drainage prior to July 14 were considered to have occurred too early to obtain a useful abundance index. Likewise, surveys occurring after July 26 were considered to have occurred too late. And, surveys with an overall rating of "poor" were considered to be poor indices of overall spawner abundance. These three aerial surveys (1981, 1986, and 1988), on average, accounted for 56% of the total abundance of spawning summer chum salmon in those years. This expansion factor was applied to other years in the data set when total escapement had not been directly enumerated but aerial surveys rated as good or fair within the period of July 14-26 had been conducted. Estimates of total escapement derived with this procedure are estimated to have an associated 8% average error. Use of this expansion factor provided an additional seven annual total escapement estimates for the East Fork of the Andreafsky River.

There have been no direct on-the-grounds total enumeration estimates of the summer chum salmon spawning escapements in the West Fork of the Andreafsky River. However, aerial surveys of the summer chum salmon spawning populations have been made in most years since 1972. Assuming similar run timing and visibility factors, the average East Fork Andreafsky River expansion factor was applied to West Fork Andreafsky River surveys meeting the temporal and survey rating criteria. This procedure resulted in 13 annual total abundance estimates in the 29 years since 1972. Next, it seemed reasonable that abundance trends in both forks of the Andreafsky River should be similar and hypothesis tests confirmed this conjecture. Based upon total abundance estimates already discussed, there were nine years when total escapement estimates were available for both populations; a regression of these paired data found that the slope of the relationship was 0.9397, significant at the 0.00011 level. This relationship was then used to estimate total abundance in one spawning population when a total

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estimate was available for the other. Associated average percent error associated with this procedure was estimated at 28% and the methodology was used to calculate four additional total escapement estimates for the East Fork Andreafsky River population and 12 additional total abundance estimates for the West Fork Andreafsky River population. These procedures left the years 1989, 1990, 1992, and 1993 as the only years in the 1972-2000 data set without total escapement estimates. A complete set of total escapement estimates is available for the Anvik River summer chum salmon population which is located at mile 317 on the Yukon River. A regression analysis of the annual Anvik River escapement estimates with the summed East and West Fork Andreafsky River escapement estimates resulted in an estimated slope of 0.23598, significant at the 0.0298 level. Use of this relationship was estimated to have an associated 33% average error and the procedure was used to develop estimates for the four years in the Andreafsky River data set without total escapement estimates from prior methods.

Andreafsky River origin summer chum salmon are caught in commercial and subsistence fisheries in the lower two districts of the Yukon River. There are no stock identification or other programs currently in place that can be used to allocate the catches in the Yukon fisheries to stock of origin. However, available data support the hypothesis that about one-half of the catch in districts downstream of the mouth of the Anvik River have been Anvik origin summer chum salmon. Given that apportionment, estimates of the total exploitation of Anvik River origin summer chum salmon were calculated for each of the Yukon fishing districts. Next it was assumed that the Andreafsky River origin summer chum salmon stock has been exploited at the same rate as the Anvik River origin stock in fishing districts where they co-mingle. These annual district specific exploitation rates were summed to estimate total annual exploitation rates and these data coupled with annual escapement estimates were used to estimate annual catches and annual total runs. Estimates of age composition in Andreafsky River escapements and in mixed stock Yukon River fisheries provided the additional information needed to estimate age specific total runs, and thus, to estimate a 1972-1995 brood table for the overall Andreafsky River summer chum salmon stock.

Analysis of the 1972-1995 brood table showed that 10 of the 24 brood year escapements of Andreafsky River summer chum salmon failed to replace themselves. There were eight years during this 24-year period when escapement exceeded 300,000 spawning fish and in six of those years, the stock failed to replace itself, indicating density dependent mortality. A Ricker-type stock-recruit model was fit to these data; the relationship was significant at the 0.0098 level and the maximum sustained yield (MSY) escapement level was estimated to be 161,047 spawning summer chum salmon in the combined East and West Forks of the Andreafsky River. This model estimates maximum sustained yield of Andreafsky River system summer chum salmon as 124,418 fish. The model suggests MSY exploitation rate at 44% is a relatively low rate compared to other studied salmon populations.

However, the residuals in the stock-recruit relationship developed with brood year 1972-1995 data showed some disturbing patterns, casting some doubt on estimates derived from the relationship. Casual observation of the residuals shows a pattern that appears less than random. However, a statistical test suggests these data are not auto-correlated. Residuals in the relationship are mostly negative after 1976, except for minor positive residuals in 1981, 1984, and 1987 and a large positive residual in 1990. Without the large positive residual, it would be

fairly apparent that a trend in the data existed and that the data should be split with emphasis on the period of the 1980s and 1990s. Additionally, various ADF&G staff supports the belief that the aerial surveys that took place in the 1970s were biased high relative to current survey methodology and results.

Thus, the major conundrum associated with this analysis is whether to rely on the full data set of brood years 1972-1995 or to rely on a shorter data series where the suspect 1970s surveys are not included in the analysis. A complete analysis only using data from 1981 to 2000 was completed. Relevant aspects of that analysis included residuals with a random pattern thus addressing the largest concern with the full 1972-1995 data set. Contrast in escapements used to build the 1981-1995 relationship was only 4.2 compared to the contrast of 8.6 for the full data set. The estimated MSY escapement level for the 1981-1995 data set was 102,592, about 64% of the level estimated with the full data set. Thus, the concern with residuals could be addressed, but only with a data set with relatively low contrast in escapements and the decision as to which data set to use has a great influence on the statistic of most interest, MSY escapement level. Because the residuals in the original relationship are not statistically auto-correlated and the apparent trend is still somewhat murky, I have decided to support the 1972-1995 data set and relationship as the best available scientific information. However, I caution the reader that there are good technical reasons to believe that this approach leads to a positively biased MSY escapement goal. There is compelling, although not overwhelming scientific evidence to support an MSY escapement point goal of about two-thirds the level identified in this report (about 100,000 in total, or about 50,000 per fork in total, or about 30,000 per fork with aerial surveys).

A discussion of review comments of this work is included along with my response to these comments. Recommendations concerning improved stock assessment of Andreafsky River summer chum salmon are provided in this report, including the recommendation to initiate an on-the-grounds total enumeration project for summer chum salmon in the West Fork. Based upon the spawner-recruit relationship developed in this report, it is recommended that the following biological escapement goals be formally adopted by the Alaska Department of Fish and Game:

East Fork of the Andreafsky River: 65,000 to 130,000 total spawners or 35,000 to 70,000 counted in an aerial survey.

West Fork of the Andreafsky River: 65,000 to 130,000 total spawners or 35,000 to 70,000 counted in an aerial survey.

Examination of past escapement trends indicates that the two Andreafsky River stocks of summer chum salmon have achieved escapements less than the ranges recommended in this report in about 25% of the years since 1972 and in about 50% of the years since 1990. However, if the data set based on 1981-1995 had been chosen as the basis for recommended biological escapement goals, only the 1999 and 2000 escapements in the 20-year history (10%) would have been below the recommended range. Thus the uncertainty with regard to the best data set to use to estimate the MSY escapement level carries over into any evaluation of stock status of the Andreafsky River summer chum salmon stock. The approach chosen in this paper is risk-adverse. But the approach likely comes at a cost to fishing opportunity and as indicated above, a

strong technical case can easily be made for a less risk adverse approach with an accompanying recommended biological escapement goal of about two-thirds the level recommended in this report.

Given the uncertainty, it is recommended that this analysis be updated in two years (in 2002). And, this report's recommended biological escapement goals should be sun-setted at that time pending further analysis. At that time, the 1997 escapement could be included; it will be the second smallest escapement and it may influence the relationship. Secondly, on-the-grounds escapement estimates recommended herein for the West Fork Andreafsky River may affirm or reject total escapement estimation methodology used herein. Third, at that time, residuals will again need to be closely examined to determine if trends are strong enough to make technical decision on appropriate data to include in the analysis.

KEY WORDS: chum salmon, *Oncorhynchus keta*, Andreafsky River, Yukon River, brood table, biological escapement goal, maximum sustained yield, spawner-recruit relationship

INTRODUCTION

The Andreafsky River is a large, first order tributary to the Yukon River. The confluence of the Andreafsky and Yukon Rivers is located 104 miles upstream of the mouth of the Yukon River. The Andreafsky River has two major forks, the East Fork and the West Fork with each supporting a major spawning stock of summer chum salmon *Oncorhynchus keta*.

The Andreafsky River stock of chum salmon is likely the largest spawning stock of summer chum salmon in the lower portion of the Yukon River drainage (lower 200 miles of drainage). Andreafsky River summer chum salmon have been assessed since 1972, although stock assessment methodology has varied over the past three decades. From 1981 to 1984, side-scan sonar was used to enumerate escapement of summer chum salmon in the East Fork Andreafsky River. From 1986-1988, a tower was used to enumerate summer chum salmon in the East Fork Andreafsky River. And, from 1994-2000, a weir or counting fence was used to enumerate summer chum salmon in the East Fork Andreafsky River. In most years since 1972, aerial surveys have been conducted to index spawning escapements of summer chum salmon in the East and the West Fork of the Andreafsky River.

The Alaska Department of Fish and Game (ADF&G) has managed the salmon fisheries in the Yukon River over the past few decades with the dual goal of maintaining important fisheries while at the same time achieving desired escapements. Escapement objectives for the Andreafsky River chum salmon population have been in effect over the past 20 years. Buklis (1993) provides the following narrative concerning the historical background for the various escapement goals that ADF&G used for the Andreafsky River chum salmon stock through the year 1992:

> "*A summer chum salmon aerial survey escapement goal of 160,000 was proposed in 1979 for the East and West Fork of the Andreafsky River combined. In April 1982 an escapement goal of 100,000 summer chum salmon for each fork of the Andreafsky was proposed. In April 1984 an escapement goal range was established for each fork: 76,000 to 109,000 for the East Fork and 62,000 to 116,000 for the West Fork (reference: ADF&G. 1984. Yukon Area 1984 annual management report. ADF&G, Commercial Fisheries Division). In 1988 the goals for each fork were taken as the upper end of the ranges, i.e., 109,000 for the East Fork and 116,000 for the West Fork (reference: Whitmore, C. and six co-authors. 1990. Yukon Area annual management report, 1988. ADF&G, Commercial Fisheries Division, RIR 3A90-28).*"

Buklis (1993) also provides the escapement goal used for the Andreafsky River chum salmon stock in 1992 as:

> "*>109,000 aerial survey count for the East Fork*
> *>116,000 aerial survey count for the West Fork*"

And, Buklis (1993) provides the following narrative as the method for establishing the goals in effect in 1992 as:

In 1994, Sandone (1994) recommended that the East Fork Andreafsky River summer chum salmon escapement goals be lowered from a minimum of 109,000 aerial survey counts to a level of 100,000 aerial survey counts based on a revised escapement averaging approach. And, Sandone (1994) also recommended that the West Fork goal be changed from a minimum of 116,000 to a level of 120,000 aerial survey counts based on revised escapement averaging methodology. Later in 1994, Sandone and Bergstrom (1994) concluded that the aerial survey goals earlier identified were too high based upon a run reconstruction procedure and they recommended a total escapement goal for the East Fork Andreafsky River of 110,000 spawners. In 1999, Huttunen and Bergstrom (1999) recommended an escapement goal range of 88,000 to 176,000 chum salmon for the East Fork Andreafsky River counted through the weir. Huttunen and Bergstrom (1999) also recommended an aerial survey goal of 64,000 to 128,000 chum salmon in the East Fork and 48,000 to 96,000 in the West Fork, again by escapement averaging methodologies.

This report is written to document current analyses relevant to developing a stock-recruit relationship for the Andreafsky River summer chum salmon stock and to make recommendations to ADF&G as to appropriate biological escapement goals for this important stock of summer chum salmon.

ANDREAFSKY RIVER SUMMER CHUM SALMON ESCAPEMENTS

A significant challenge in reconstructing the Andreafsky River chum salmon runs and developing a stock-recruit relationship for the stock is development of annual total escapement estimates for the East and West Fork spawning populations. Four general methodologies were used to address this challenge. First, total abundance estimates that were available were used. For the 29-year period of 1972-2000, there were four annual side-scan sonar based total estimates, three annual tower based total estimates, and seven annual weir based total estimates for chum salmon that spawned in the East Fork of the Andreafsky River (48% of the years). Estimates of measurement errors associated with these total enumeration estimates are unknown, but assumed small. Second, an expansion factor was developed based upon the paired data set of complete escapement enumeration estimates and surveys of escapements when surveys were rated as "good" or "fair" and when the survey took place between July 14 and 26. An additional seven annual total escapement estimates for the East Fork population and thirteen total escapement estimates for the West Fork population were developed with this aerial survey expansion method. Only "good" or "fair" rated surveys between July 14 and 26 were expanded in this manner. Associated absolute average percent error with the survey expansion approach was estimated at 8%. Third, a regression of annual total escapement estimates derived from the first two methodologies for the East and West Fork spawning populations provided a statistical means of estimating one fork's spawning population in a year when a total escapement estimate was available from the other fork. This "East-West" regression approach was estimated to have

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an associated 28% average percent error and the method was used to develop four East Fork and twelve West Fork total escapement estimates. The last method of estimating total annual escapements involved a relationship between the Anvik River stock of summer chum salmon escapements and the summed East and West Fork escapements as already developed from the first three methodologies. This "Anvik versus Summed Andreafsky" relationship had a slope of 0.2359 and that slope, coupled with Anvik River summer chum salmon escapement estimates, was used to develop Andreafsky River total escapements for the years 1989, 1990, 1992, and 1993. Average absolute percent errors associated with the "Anvik-Summed Andreafsky" method was estimated to be 33%. Plots of the two regressions are provided in Figure 1. Details concerning these methodologies are provided in the following sections.

Aerial Survey Expansion Method

As described above, total escapement estimates for summer chum salmon spawning in the East Fork of the Andreafsky River were available for 14 of the 29 years from 1972-2000 based upon side-scan sonar, tower, or weir operations. In seven of those fourteen years, an aerial survey of the East Fork resulted in a count of chum salmon observed (Table 1). Unfortunately, several most of those aerial surveys were either flown too late to represent a valid index of chums because they were directed at enumeration of chinook salmon (1987 and 2000) or the aerial survey observer rated the survey as a "3" or "poor" (1982 and 1984). The remaining annual aerial surveys in the paired database, 1981, 1986, and 1988 resulted in 55.4%, 50.1%, and 62.5% of the total estimated escapement being observed during the survey, respectively, with the average being 56.0% (Table 1). These three aerial surveys took place between July 14 and 23 and based upon aerial survey observer comments concerning timing of surveys, I defined July 14-26, a 13-day period as an appropriate window of opportunity for application of the average expansion factor. These three surveys were rated as "1" or "good" (1988) or as "2" or "fair" (1981 and 1986); hence, I decided to limit application of the survey expansion method to only surveys rated as "good" or "fair".

Application of the aerial survey method to the three years of total estimates from which it was derived indicated that the method has an associated 8% average error (Table 2). The method was applied to aerial surveys of the East Fork Andreafsky River when those surveys took place from July14-26 and when the surveys were rated as "good" or "poor". These criteria allowed for an additional seven total escapement estimates to be developed for the East Fork Andreafsky River summer chum salmon population from 1972-2000 (Table 3).

There are no on-the-grounds based total estimates of escapement available for the West Fork of the Andreafsky River. I elected to apply the aerial survey method developed for the East Fork Andreafsky River population directly to the West Fork. I have no way of determining whether such application results in estimates that are correct, are biased low or are biased high. And, until such time as total escapement estimates of the spawning population in the West Fork of the Andreafsky River are undertaken, the appropriateness of the assumption I have made in this report cannot be determined. Inherent assumptions I have made include similar run timing and similar visibility factors. Application of the methodology to the West Fork aerial survey database, again limiting application to surveys conducted from July 14-26 and confined to those

with an overall rating of "good" or "fair" resulted in the development of thirteen annual escapement estimates (Table 4).

Utility of the aerial survey expansion approach that I have used to estimate historic total escapements in the East and West Forks of the Andreafsky River could be greatly enhanced in future years with improved stock assessments. Specifically, additional aerial surveys of chum salmon in the East Fork during the time period of July 14-26 are recommended to gain a better appreciation of an appropriate expansion factor and the variables that likely influence the portion observed from the air. Secondly, an on-the-grounds approach to estimating escapement strength of the West Fork population is sorely needed. Third, the recent trend of not flying surveys of either fork (lack of any surveys from 1994-1999, see Tables 3 and 4) has greatly limited the ability of anyone to evaluate stock status of these important stocks of summer chum salmon in recent years.

East-West Regression Method

From the methodology discussed above, 21 annual total estimates for the East Fork Andreafsky River escapements and 13 annual total estimates for the West Fork Andreafsky River escapements were developed. From this data set, there were nine years when total estimates of escapement were available for both forks (Table 5). These two annual data sets were highly correlated (correlation = 0.9397, significant at the 0.005 level). Therefore, a regression with the intercept set at zero was constructed, the resultant relationship was found to be significant at the 0.00011 level, and the estimated slope was 0.9753293 (Figure 1). From this relationship, two estimation processes were developed: (1) East Fork total escapement = West Fork total escapement/0.9753293 and (2) West Fork total escapement = East Fork total escapement * 0.9753293. Application of this methodology to the nine years of data from which it was derived indicated average percent error for the East Fork estimates was 27% and average percent error for the West Fork estimates was 28% (Table 6).

Application of the East-West Regression method resulted in an additional four total escapement estimates for the East Fork Andreafsky River population (Table 7) and twelve additional total estimates for the West Fork Andreafsky River population (Table 8). In the case of the East Fork calculations, the total estimates derived from the East-West Regression methodology greatly exceeded aerial counts of fish from surveys in 1973, 1974 and 1980. Those surveys were "late" and rated "poor", "early" and not rated, or within the prescribed time period but rated as "poor", respectively (Table 7). These are the results one would expect, however, the result for the 1978 estimate is not. In 1978, an aerial survey on July 11 rated as "fair" counted 127,050 chums while the East-West regression procedure estimates the total escapement to have been less, at 105,015 chum salmon (Table 7). Perhaps some of the fish observed on the July 11, 1978, survey backed downstream and went elsewhere to spawn. Or perhaps, the time period I chose for application of the aerial survey expansion methodology was too conservative and it should have been moved back a couple of days to pick up this and other surveys that just missed my prescribed timing window of opportunity by a couple of days. Unfortunately, one can only speculate as the only way to know for sure is if the total escapement in 1978 would have been estimated with on-the-grounds procedures.

In the case of the West Fork Andreafsky River calculations, the total estimates derived from the East-West Regression methodology exceeded counts of chum salmon from surveys in 1972, 1982, and 2000. Those surveys were within the designated time period but rated as "poor" in 1972 and 1982 and considered "late" but rated as "good" in 2000. Again, these are the results one would expect. However, the result for the fourth West Fork estimate is not. In 1984, a survey rated as "good" but conducted "early" counted 238,565 chum salmon while the East-West Regression methodology estimated that total escapement in that year was only 68,395, less than 30% of the aerial survey estimate (Table 8). Again, I conjecture that most of the fish observed on the July 13, 1984 aerial survey of the West Fork backed downstream and went elsewhere to spawn. Again, however, it may be that the time period I chose for application of the aerial survey expansion methodology was too conservative. Perhaps my timing criteria should have been moved back a couple of days to pick up this and other surveys that just missed my prescribed timing window of opportunity by a couple of days. As in the East Fork Andreafsky River, the only way to know for sure is if the total escapement in the West Fork in 1984 had been estimated with on-the-ground methodology.

Anvik-Summed Andreafsky Regression Method

Both total escapement estimation procedures as described above resulted in estimates for all years from 1972-2000 except for 1989, 1990, 1992, and 1993. With no direct information, I examined the relationship between the estimated escapements of summer chum salmon in the Anvik River and the sum of estimated escapements in the East and West Forks of the Andreafsky River (Gene Sandone, ADF&G, Anchorage, personal communication). Paired data available for the years 1981-2000 were examined (Table 9) and found to be significantly correlated (correlation = 0.5896, significant at the 0.01 level). A regression with the intercept set at zero was constructed and the resultant relationship was found to be significant at the 0.0298 level with an estimated slope of 0.23598245 (Figure 1). This relationship was used to predict summed Andreafsky summer chum salmon escapements as Anvik total escapement * 0.23598245. The relationship between East and West Fork total escapements was subsequently used to split the summed estimate derived from the Anvik-Summed Andreafsky Regression method into component parts.

The Anvik-Summed Andreafsky Regression procedure, when applied to the 16 year database from which it was developed, estimated that average percent error associated with this procedure was 33% (Table 10). This procedure was used to estimate total escapements of summer chum salmon in the East and West Forks of the Andreafsky River for the years 1989, 1990, 1992, and 1993 (Tables 11 and 12). In all four cases for the East Fork estimates, the Anvik-Summed Andreafsky approach resulted in total escapement estimates well above the counts observed during aerial surveys. These are the results one would expect given that in two of those years, the surveys were rated as "poor" and "early", in another the survey was rated as "poor" while timing fit within the prescribed limits, and the fourth was rated as "good" but early (Table 11). In the case of the four West Fork estimates, no survey of the West Fork took place in one year (1989) and in the other years, the aerial surveys accounted for far fewer fish than were estimated as total escapements. Again, this would be expected given those surveys were either "early" or rated as "poor" or both (Table 12).

Andreafsky River Total Escapements of Summer Chum Salmon

A discussion of the escapement estimation procedures employed above may be helpful to the reader before proceeding further. Only a minority of total escapement estimates in this report were derived from on-the-ground sampling efforts (14 of 58 or 24% of the estimates). The other 76% of total escapement estimates were developed based upon at least one of three alternate procedures with some estimates being dependent upon other estimates. A technical case could be made for not including some of the available 14 total escapement estimates based on the on-the-ground enumeration methods that I included. My response is that I preferred to use the total escapement estimates that were developed from actual sampling data over aerial survey expansion or other total estimation procedures.

The criteria I defined for application of the aerial survey expansion methodology directly influenced what proportion of the available aerial surveys are directly expanded and what the calculated expansion factor is. I took a very conservative view of the available expansion data and limited the subsequent aerial survey data that was expanded. A case might be made for extending the July 14-26 criteria that I used by a couple of days. However, I believe this would only effect a few total escapement estimates and only one by a significant degree; specifically, the West Fork estimate in 1984. One would be hard pressed to make a solid technical case for including other available years in the survey expansion average value.

The estimates I developed were based upon the pathway I took through the two regression processes, alternate pathways even if chosen carefully, could have resulted in somewhat different total escapement estimates. Others trying to develop total escapement estimates for the East and West Fork Andreafsky River chum salmon populations from the available data might have gone about it differently and ended up with somewhat different total escapement estimates for the summed population. But, because I used significant relationships to retain escapement magnitudes and trends, alternate pathways would have resulted in only minor changes in the overall magnitudes and trends of estimated total escapements. Lastly, I have made efforts to provide the reader with estimates of likely sampling errors associated with the various escapement estimates developed so that the reader can make independent judgements concerning validity of these estimates.

It is important to note that the escapement estimates developed in this report are believed to be reasonable. But, just how reasonable they are cannot ever be definitely answered because for the most part, these escapements were not closely monitored. Instead, aerial surveys were conducted to index escapement strength in most years while in other years and particularly for the West Fork Andreafsky River, there are complete voids in the historic stock assessments. The strength of this analysis is not how well I have estimated these individual spawning escapements, but whether or not the escapement magnitudes and trends, when combined for both spawning populations, reflect actual run strength of the Andreafsky River summer chum salmon escapements. Even in recent years, when a consistent weir escapement enumeration effort has been in place in the East Fork Andreafsky River, this cannot be reaffirmed very well, as the West Fork population has, for the most part, not been monitored with aerial surveys. That said, I encourage others to develop run re-constructions and total escapement estimates for these stocks

of summer chum salmon as an independent means of affirming or rejecting the overall historic escapement magnitudes and trends that I have developed herein.

Total annual escapements of Andreafsky River summer chum salmon were estimated for the years 1972-2000 by summing annual chum salmon escapement estimates already described earlier in this report for the East and West Forks. Estimated annual escapements ranged from a low of 46,122 chum salmon for 2000 to a high of 820,949 chum salmon for 1975, averaging 228,234 chum salmon per year over the 29-year period. The contrast in spawning escapements over this period was about 18-fold. However, the escapement contrast from brood years 1972-1995 (brood years used in the spawner-recruit relationship) was 8.6-fold because the smallest total escapement in those years was 95,249 in 1990. This is a meaningful level of variation or contrast in annual spawning abundance. According to the Chinook Technical Committee (CTC) (1999), the following guidelines concerning contrast in spawning abundance can be used in statistical stock-recruit analyses:

> *"When estimates of spawning abundance are similar – the range is less than 4 times the smallest spawning abundance – statistical stock-recruit analysis is likely to produce a poor estimate of S_{MSY}.*
>
> *When range in spawning abundance is 4 to 8 times the smallest level, statistical stock-recruit analysis should produce better estimates of S_{MSY}, so long as measurement error is not extreme and some of the production-to-spawner ratios are below one at higher levels of spawning abundance.*
>
> *When range is more than 8, statistical analysis should produce the best estimates, so long as some of the production-to-spawner ratios are below one at higher levels of spawning abundance."*

With a contrast of spawning escapements of about 8.6-fold, the Andreafsky River chum salmon analysis fits into the third category identified by the CTC (1999) general methods. Therefore, production-to-spawner levels are important in determining if data will be adequate to conduct a statistical analysis. As noted later in this report, 24 brood years of recruits are estimated and eight of the estimated escapements exceeded 300,000 spawners, with six of those failing to replace themselves. Thus, the criterion associated with the third category is met for the Andreafsky analysis. Although the CTC does not address measurement errors in the third category, it is still an important aspect and measurement errors should not be extreme. The issue of measurement errors associated with the Andreafsky River data set is a more difficult problem to assess. The individual total estimated escapements derived in this report have an average absolute error of 33% or less, according to analysis already presented. Therefore, it seems very unlikely that measurement errors associated with these annual Andreafsky River estimates of total chum salmon escapements could be considered extreme. Given this logic, there is good reason to believe that the conditions listed by the CTC (1999) for statistical stock-recruit analyses are met. Thus there are good technical reasons to believe that the Andreafsky summer chum salmon stock-recruit analysis will lead to useable estimates of the escapement level that produces maximum sustained yield (S_{MSY}).

EXPLOITATION RATE OF ANDREAFSKY RIVER
SUMMER CHUM SALMON

There are no stock identification projects in place providing estimates of the stock composition of summer chum salmon caught in the mixed stock fisheries in the lower portion of the Yukon River. Nor are there any large-scale tagging results or other scientific information available that provides annual estimates of the proportion of Andreafsky origin chum salmon in these mixed stock fisheries of the Yukon River. There is however, a scientific basis for estimating the proportion of Anvik origin chum salmon in lower Yukon River fisheries. The procedure is based upon run reconstruction methodology using counts of chum salmon by sonar at Pilot Station, counts at the Anvik River sonar enumeration site and catches of chums by district (Clark and Sandone 2001). The approach taken in this report was to assume exploitation rates (by lower Yukon River fishing district) estimated for the Anvik River stock of summer chum salmon is a reasonable proxy measure for the Andreafsky River summer chum salmon stock. Available information in support of this assumption is the fact that the same fishermen harvest both stocks in mixed stock fisheries of the lower Yukon River with the same gear. Available information that would question the assumption is that run timing of these two summer chum stocks salmon is different.

In the 14 years between 1981 and 2000, when on-the-grounds enumeration of the East Fork Andreafsky chum salmon stock occurred, the mid-point of the spawning run occurred on July 6. During those very same years, the mid-point of the run enumerated at the Anvik River sonar site was also July 6. However, the Andreafsky River mouth is at mile 104 and the weir site is located 26 miles upstream while the mouth of the Anvik is located at mile 318 with the sonar site another 47 miles upstream. Thus the Anvik River summer chum salmon run has the same mid-point run date as the Andreafsky summer chum salmon run while it migrates an additional 214 miles. Consequently, the Anvik River summer chum salmon run has to pass through lower Yukon River fisheries earlier, on average than the Andreafsky River run. As a result of run timing differences, the assumption that exploitation rates of Anvik origin summer chum salmon are reasonable proxy estimates of the exploitation rate of Andreafsky origin fish is tied up with relative fishing patterns throughout the season. In other words, if fishing effort is similar for both stocks, the assumption is valid even though the two stocks have different run timing. However, if fishing effort in the lower Yukon River is skewed early, the Anvik stock would be more heavily exploited and if skewed late, the Andreafsky stock would be more heavily exploited. Only if very significant trends in fishing effort across the 1972-2000 time period occurred, would these potential differences in exploitation rates be substantial. It is beyond the scope of this report to evaluate relative fishing effort in lower Yukon River fisheries. But, I wanted to alert the reader to reasons to support or refute my assumption that Anvik origin estimated exploitation rates in lower Yukon River fishing districts are reasonable proxy rates for the Andreafsky stock.

Estimates of Anvik River summer chum salmon escapements and in-river harvests and estimates of the total mixed stock summer chum salmon harvests in Yukon River fishing Districts 1-4 are provided in Table 13. The Clark and Sandone (2001) report indicates that about one-half of the mixed stock catch in Yukon fishing Districts 1, 2, and 3 are Anvik origin fish while about 15% of the catch in District 4 is of Anvik origin (Table 14). Use of this stock allocation scheme leads

to estimates of the annual exploitation rates of Anvik origin summer chum salmon in each fishing district of the lower Yukon River (Table 15).

The Andreafsky River joins the Yukon River about a third of the way upstream in fishing District 2. Fishing District 2 is split into five subdistricts and the mouth of the Andreafsky is close to the boundary of Subdistricts 334-22 and 334-23. Relative annual catches in the two downstream versus three upstream subdistricts was used to adjust Anvik based total exploitation in fishing District 2 into estimates of that in the portion of the district downstream of the mouth of the Andreafsky River. Catches in the two downstream subdistricts (334-21 and 334-22) averaged 59.1% of the total fishing District 2 catch of summer chum salmon in the years 1983-1999. These annual data were used to apportion the catch in fishing District 2 in those years. Annual values for the years 1972-1982 and 2000 were based on the average value obtained for the years 1983-1999. These calculations resulted in annual total exploitation rates for Andreafsky River origin summer chum salmon (Table 16). Estimated total exploitation of Andreafsky River summer chum salmon ranged from a low of 5% in 1999 to a high of 39% in 1983, averaging 21% over the 29-year period of 1972-2000.

AGE SPECIFIC TOTAL RUNS OF ANDREAFSKY RIVER SUMMER CHUM SALMON

Estimates of the annual summed East and West Fork Andreafsky River summer chum salmon escapements discussed earlier, and the annual estimated total exploitation rates just discussed were used to estimate annual catches and total runs of Andreafsky origin summer chum salmon from 1972-2000. Total runs of Andreafsky River origin fish were estimated to have ranged from a low of 49,815 summer chum salmon in 2000 to a high of 1,040,135 summer chum salmon in 1975, averaging 295,496 salmon in the 29-year period of 1972-2000 (Figure 2 and Table 17).

Age composition of summer chum salmon escapements in the East Fork Andreafsky River has been monitored based upon an active sampling program since 1982 with sample sizes of aged fish averaging 603 fish per year (Table 18). The average age composition of 0.9% age-3, 55.5% age-4, 41.0% age-5, and 2.6% age-6 fish was used as a proxy estimate of age composition of summer chum escapements in the years 1972-1981. It was assumed that the age compositions estimated for the East Fork spawning population were directly applicable to the West Fork spawning population. Multiplication of the total escapement estimates as provided in Table 17, second column, by the annual escapement age compositions provided age specific escapement estimates for the years 1972-2000.

Age composition of summer chum salmon catches in Yukon River fisheries has been monitored since 1972 with estimates based upon an active sampling program with sample sizes averaging over 2,000 aged fish per year (Table 19). The average age composition of 3.9% age-3, 57.2% age-4, 37.3% age-5, and 1.6% age-6 fish was used as a proxy estimate of age composition of summer chum catches in the years 1999-2000 because estimates for those years were not yet available. Multiplication of the total catch estimates as provided in Table 17, third column, by the annual catch age compositions provided age specific catch estimates for the years 1972-2000.

The age specific escapement and catch estimates for the Andreafsky River summer chum salmon population were added to estimate age specific total runs. The number of Andreafsky origin summer chum salmon recruits resulting from individual brood year escapements (i) was estimated as the summation of estimated total returns of age-3 fish in year $i+3$, age-4 fish in year $i+4$, age-5 fish in year $i+5$, and age-6 fish in year $i+6$. This calculation procedure resulted in estimates of total recruits from the 1972-1995 broods ranging from a low of 44,804 recruits from the 1995 brood to a high of 591,647 recruits from the 1976 brood (Table 20).

ANDREAFSKY RIVER SPAWNER-RECRUIT RELATIONSHIP

A paired data set was defined that consisted of the estimated total escapements of Andreafsky origin summer chum salmon from 1972-1995 (Table 20, column 2) and resultant recruits from those escapements (Table 20, column7). Once the paired data set was calculated, a spawner-recruit relationship was developed by fitting the paired data set to the following model:

$$R_y = \alpha S_y e^{-\beta S_y} \exp(\varepsilon_y) \tag{1}$$

where: R_y = estimated total recruitment by brood y;
S_y = spawning escapement that produced brood y;
α = intrinsic rate of population increase in the absence of density-dependent limitations;
β = density-dependent parameter; and
ε_y = process error with mean 0 and variance σ_ε^2.

This model, commonly referred to as a Ricker recruitment curve (Ricker 1975), has two parameters, α and β, to estimate, given a series of spawner and resultant recruitment observations or estimates. I assumed the errors were log-normal (as is common for salmon returns), resulting in the log-transformed linear equation:

$$\ln(R_y/S_y) = \ln(\alpha) - \beta S_y + \varepsilon_y \tag{2}$$

Linear regression procedures provided estimates of the intercept (ln α) and the slope (β) in equation 2. Hilborn and Walters (1992:271-2) published the following empirical approximation of the estimated spawning size that produces maximum sustained yield or MSY (S_{MSY}) as a function of estimated parameters:

$$\hat{S}_{MSY} \cong \frac{\ln\hat{\alpha} + \hat{\sigma}_\varepsilon^2/2}{\hat{\beta}}[0.5 - 0.07(\ln\hat{\alpha} + \hat{\sigma}_\varepsilon^2/2)] \tag{3}$$

where: $\hat{\sigma}_\varepsilon^2$ = the mean square error from the regression.

Analysis of the spawner-recruit relationship (Figure 3) resulted in an estimate of 161,047 spawners as the MSY escapement level for the Andreafsky River stock of summer chum salmon

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(Table 21). The spawner-recruit relationship developed estimated that maximum surplus yield from the Andreafsky stock of summer chum salmon is 124,418 fish, on average. If the Andreafsky stock of chum salmon were managed at the indicated MSY escapement level of 161,047 spawners per year, a fishery yield of 124,418 fish is estimated to be provided, on average, indefinitely. The exploitation rate in this case would be 44%, a relatively low exploitation rate relative to other studied salmon populations.

Inspection of Figure 3 reveals that the 1975 data point likely has a significant impact on the overall relationship, and thus upon estimated MSY escapement level. The 1975 estimated escapement is about twice that of any other escapement in the 24-year data set. The 1975 total escapement estimate was derived from an expansion of aerial surveys on July 22nd of the East and West Forks of 223,485 and 235,954, respectively (Tables 11 and 12). About 460,000 summer chum salmon were counted from the air and the expansion methodology elevated the estimate to a total of 820,949 fish (Table 20). The July 22nd aerial survey of the East Fork spawning population in 1975 was about double that of any other aerial survey in the past 29 years (Table 1). A large aerial survey escapement estimate, similar to in magnitude to the July 22, 1975 aerial survey of the West Fork was observed again in 1984. Although timing of the 1984 survey was early, that survey was not used to develop a total escapement estimate, as discussed earlier in this report (Table 12). Thus, one could make a case for considering the 1975 data point an outlier. I elected to retain the data point, as it was based on direct observation, albeit, from an aerial survey, not an on-the-grounds total estimation procedure.

The residuals in the stock-recruit relationship developed with brood year 1972-1995 data showed some disturbing patterns, casting some doubt on the MSY escapement estimate derived from the relationship (Table 22). Casual observation of the residuals (Figure 4) shows a pattern that appears less than random. However, a statistical test suggested these data are not auto-correlated (Figure 5). Residuals in the relationship are mostly negative after 1976, except for minor positive residuals in 1981, 1984, and 1987 and a large positive residual in 1990. Without the large positive residual, it would be fairly apparent that a trend in the data existed and that the data should be split with current emphasis on the period of the 1980s and 1990s. In other words, it almost looks as if some kind of regime shift occurred, starting in the late 1970s that caused production to be above average before the shift and below average after the shift. A basic tenet of using historic stock-recruit information from salmon stocks to estimate productivity and to estimate the maximum sustained yield escapement goal for use in future fishery management is that the past is representative of the future. It is not clear that this basic tenet is met for the Andreafsky analysis and it may very well be that the data from the 1970s is not an appropriate data set for use in setting a current biological escapement goal. Additionally, various ADF&G staff support the contention that the aerial surveys that took place in the 1970s were biased high relative to current survey methodology and results.

Thus, the major conundrum associated with this analysis is whether to rely on the full data set of brood years 1972-1995, or to rely on a shorter data series where the suspect 1970s surveys are not included in the analysis and where more stability in productivity is indicated. A complete re-analysis of the information already presented in this report only using data from 1981 to 2000 was completed. In the re-analysis, the East Fork Andreafsky River estimates were derived as follows: 14 from on-the grounds procedures (70%), 2 from survey expansions (10%), and 4 from

a revised Anvik-Summed Andreafsky Regression (20%). The revised West Fork Andreafsky River estimates were derived as follows: 5 from expanded aerial surveys (25%), 11 from a revised East-West Regression (55%), and 4 from the revised Anvik-Summed Andreafsky Regression (20%). The 1981-1995 data set had a much-reduced level of contrast in escapements, going from the earlier contrast of 8.6 to a level of 4.2, a marginal contrast level for stock-recruit analysis, according to the CTC (1999). The stock-recruit relationship developed from the 1981-1995 data set (Figure 6) estimated MSY escapement as 102,592 spawning chum salmon as contrasted to the 1972-1995 data set estimating this statistic as 161,047 spawning fish. The short data set indicates that the MSY escapement level is 64% of the level indicated by the full data set. The residuals associated with the short data set appear random (Figure 7), indicating that productivity across this period of time was relatively stable. Thus the concern with residuals in the 1972-1995 data set could be addressed with the shorter data set, but the solution comes at a cost of marginal contrast in escapements and the decision has a great influence on the statistic of most interest, MSY escapement level.

Because the residuals in the original relationship are not statistically auto-correlated and the apparent trend is still somewhat murky, I have decided to support the 1972-1995 data set and relationship as the best available scientific information. However, I caution the reader that there are good technical reasons to believe that this approach leads to a positively biased MSY escapement goal. And, there is compelling, although not overwhelming scientific evidence to support an MSY escapement point goal of about two-thirds the level identified in this report (about 100,000 in total, or about 50,000 per fork in total, or about 30,000 per fork with aerial surveys).

BOOTSTRAP ANALYSIS OF THE SPAWNER-RECRUIT RELATIONSHIP

The estimated variance $v(\hat{S}_{MSY})$ and 90% confidence intervals for $\hat{S}_{MSY}$ were calculated through non-parametric bootstrapping of residuals from the regression (see Efron and Tibshirani 1993:111-5). Residuals were calculated as differences between observed and predicted values:

$$\zeta_y = Y_y - \hat{E}[Y_y] \tag{4}$$

where: ζ_y = the residual for brood y;
$\quad Y_y = \ln(R_y/S_y)$;
$\quad \hat{E}[Y_y]$ = the predicted value.

A new set of dependent variables was generated by sampling the residuals from the original regression:

$$\tilde{Y}_y = \zeta_y^* + \hat{E}[Y_y] \tag{5}$$

where ζ_y^* were drawn randomly with replacement from the original vector of the n original residuals $\{\zeta_y\}$ (n = the number of brood years in the analysis). In this fashion a new data set was

created comprised of the original values for the independent variables (spawning abundance) and corresponding simulated values $\widetilde{Y}_y$. The $\widetilde{Y}_y$ were then regressed against the original values of the independent variables to produce a new, simulated set of parameter estimates for ln α, β, and σ_ε^2. These new parameter estimates were plugged into Equation (EQ) 2 to produce a simulated estimate $\widetilde{S}_{MSY}$. This process was repeated 1,000 times to produce 1,000 simulated estimates of $\widetilde{S}_{MSY}$. From Efron and Tibshirani (1993:47):

$$v(\hat{S}_{MSY}) = \frac{\sum_{b=1}^{1000}(\widetilde{S}_{MSY(b)} - \overline{S}_{MSY})^2}{1000-1} \tag{10}$$

where $\overline{S}_{MSY} = 1000^{-1}\sum_{b=1}^{1000}\widetilde{S}_{MSY(b)}$. Ninety percent confidence intervals about $\hat{S}_{MSY}$ were estimated from the 1,000 simulations with the percentile method (Efron and Tibshirani 1993:124-126). The 1,000 values of $\widetilde{S}_{MSY}$ for each scenario were sorted in ascending order making the 51st and the 950th values the lower and upper bounds of a 90% confidence interval.

The mean bootstrap estimate of MSY escapement for Andreafsky summer chum salmon was 167,217 spawners and the coefficient of variation for this mean statistic was 44% (Table 23). The 90% confidence interval for the estimated MSY escapement level for the Andreafsky River chum salmon stock is estimated at 120,381 to 234,726 spawners (Table 23). The bootstrap mean estimate of the MSY escapement level is higher than the regression estimate of 161,047 spawners, and differs by 6,170 fish, indicating bias is minor at 3.7% (Table 23).

BIOLOGICAL ESCAPEMENT GOAL
FOR ANDREAFSKY RIVER SUMMER CHUM SALMON

A maximum sustained yield escapement goal range was estimated using the 0.8 ($\hat{S}_{MSY}$), to 1.6 ($\hat{S}_{MSY}$) procedure of Eggers (1993). This method examined optimizing harvests over a wide range of management scenarios. The initial estimate of S_{MSY} was used as the point value for recommending a biological escapement goal and this biological escapement goal is expressed as a range.

I believe that the current best available scientific estimate of the MSY escapement point value for the overall Andreafsky River stock of summer chum salmon is about **160,000** spawners. Based upon the proportion of the East and West Fork spawning populations to the total, the total estimate of 160,000 spawners equates to about 80,000 spawners in both the East and West Fork. The equivalent point values, if measured in an aerial survey, would be about 45,000 spawners per fork. I believe that the biological escapement goals for summer chum salmon in both the East Fork and the West Fork of the Andreafsky River should be set at **65,000 to 130,000 total spawners** per year (combined range for both forks is 130,000 to 260,000). This range is based upon the identified best estimate of the point value and the approximate application of the methodology of Eggers (1993). This range approximately encompasses the 90% confidence

interval of MSY total escapement (about 120,000 to 235,000) based on the bootstrap analysis (Table 23).

Again, however, I want to point out that there are good technical reasons to believe that the approach I have chosen leads to positively biased MSY escapement goals. And, there is compelling, although not overwhelming scientific evidence to support MSY escapement goals of about two-thirds the level identified above (about 100,000 in total, or about 50,000 per fork in total, or about 30,000 per fork with aerial surveys). Thus the uncertainty with regard to the best data set to use to estimate the MSY escapement level strongly carries over into a recommendation regarding an appropriate biological escapement goal. The approach chosen in this paper is risk-adverse relative to lowering the existing Andreafsky summer chum salmon escapement goals far below current levels. But the approach likely comes at a cost to fishing opportunity and as indicated above, a strong technical case can easily be made for a less risk adverse approach with an accompanying recommended biological escapement goal of about two-thirds the level recommended in this report.

Given the uncertainty, it is recommended that this analysis be updated in two years (in 2002). This report's recommended biological escapement goals should also be sun-setted at that time pending further analysis. At that time, the 1997 escapement could be included; it will be the second smallest escapement and it may influence the relationship. Secondly, on-the-grounds escapement estimates recommended herein for the West Fork may affirm or reject total escapement estimation methodology used herein. Third, at that time, residuals will again need to be closely examined to determine if trends are strong enough to make a strong technical decision on the appropriate years of data to include in the analysis.

STOCK STATUS OF ANDREAFSKY RIVER SUMMER CHUM SALMON GIVEN THE RECOMMENDED MSY ESCAPEMENT GOAL

From 1972 to 2000, eight of the twenty-nine (28%) annual East Fork chum salmon escapements were below the range of escapements that are currently estimated to produce maximum sustained yield fisheries in the Yukon River (Table 24). Of the twenty-one other annual total escapements, 12 (41%) were within the range of total escapements estimated to produce maximum sustained yield fisheries while the remaining 9 (31%) were above that range. Since 1990, six of the eleven escapements (54%) in the East Fork were below the range estimated to result in maximum sustained yield fisheries, an increased probability of falling in this category over earlier years. The recent escapements in the East Fork that have been less than the recommended range (1997, 1999, and 2000) supported very light exploitation (9%, 5%, and 7%, respectively) so it is clear that over-fishing was not the reason for recent escapement short-falls. Recent escapement short-falls in the East Fork are the result of less than average production, not over-fishing in the Yukon River (Figure 4).

From 1972 to 2000, seven of the twenty-nine (24%) annual West Fork chum salmon escapements were below the range of escapements that are currently estimated to produce maximum sustained yield fisheries in the Yukon River (Table 24). Of the twenty-two other annual total escapements, 14 (48%) were within the range of total escapements estimated to

produce maximum sustained yield fisheries while the remaining 8 (28%) were above that range. Since 1990, five of the eleven escapements (46%) in the West Fork were below the range estimated to result in maximum sustained yield fisheries, again, an increased probability of falling in this category over earlier years. Again, the recent escapements in the West Fork that have been less than the recommended range (1997, 1999, and 2000) supported very light exploitation (9%, 5%, and 7%, respectively). It is clear that over-fishing was not the reason for these recent escapement short-falls. Recent escapement short-falls in the West Fork Andreafsky are the result of less than average production, not a result of over-fishing in the Yukon River (Figure 4).

It should be noted that if the data set based on 1981-1995 had been chosen as the basis for recommended biological escapement goals, only the 1999 and 2000 escapements in the 20-year history (10%) would have been below the recommended range. Thus the uncertainty with regard to the best data set to use to estimate the MSY escapement level carries over into any evaluation of stock status of the Andreafsky River summer chum salmon stock.

REVIEW COMMENTS AND AUTHOR'S RESPONSE

This and five other draft reports concerning biological escapement goals (BEGs) for salmon stocks in the Arctic-Yukon-Kuskokwim (AYK) Region of Alaska were prepared by ADF&G staff and released for public review in November and December of 2000. Two written reviews concerning the draft BEG technical reports were prepared and submitted to ADF&G. Oral and written reports concerning the six AYK BEG analysis and the two technical reviews concerning these draft analyses were submitted to the Alaska Board of Fisheries in December and January and the AYK BEG analyses became quite controversial during the January Board of Fisheries meeting. A discussion of these reviews and the ADF&G author's response to these reviews is provided herein to better inform the reader of aspects of the technical issues involved and to provide a more complete discussion of the topic. Some of the following discussion relates to the Andreafsky analysis (the topic of this report) only in a general manner while other aspects of the discussion relate directly to the Andreafsky River chum salmon BEG analysis reported herein.

Mundy et al. (2001) Review

An independent scientific peer review of data and analysis included in the six draft reports was conducted at the request of ADF&G, and on January 15, 2001, this review was completed. The 42 page written review was titled "*A Preliminary Review of Western Alaskan Biological Escapement Goal Reports for the Alaska Board of Fisheries*". Members of the peer review committee were Drs. Philip R. Mundy (Chief Scientist for Exxon Valdez Oil Spill Trustee Council and chair of the committee), Milo Adkison (University of Alaska), Eric Knudsen (United States Geological Survey), Daniel Goodman (Montana State University), and Ray Hilborn (University of Washington). These scientists have published 50 or more scientific articles on the technical topic of stock-recruit analysis. In general, their review was supportive of the analyses developed by ADF&G staff and adoption of the draft BEG goals was recommended with some revision. The committee understood the conundrum that while these

draft BEG escapement goals were not perfect and should not be considered as long-term answers to the problem, they did represent a significant improvement over the existing escapement goals for these salmon stocks of the AYK region. The committee did suggest ways that various analyses could be improved in the long run to develop better escapement goals as the existing database for these stocks gains strength through time. Arctic-Yukon-Kuskokwim (AYK) BEG authors, including myself, appreciated the committee's technical review efforts and we appreciated the committee making positive suggestions for improvement. Hereafter this independent scientific peer review will be referred to as Mundy et al. (2001).

The Mundy et al. (2001) review includes findings, recommendations, and conclusions directed generally at all six draft BEG reports and specific comments directed at individual reports. I first address the general comments in this narrative. Findings by Mundy et al. 2001 were: "(1) *Were the analyses as presented done correctly? Yes;* (2) *Were the analyses appropriate to the available data? Yes;* and (3) *Are the estimates of S_{MSY} reasonable as long-term escapement goals? No.*"

Relative to item 3 above, Mundy et al. 2001 went on to state: "*The estimates of S_{MSY} appear reasonable short-term starting points for developing adaptive strategies for setting escapement goals appropriate to protecting the long-term interests of subsistence, commercial, and other types of uses. Any escapement goals based on these analyses must take into account the uncertainty of the S_{MSY} estimates, and they would need to be revised as soon as possible based on additional analyses and types of information described in this report. Due to a number of uncertainties regarding the data, the estimates of S_{MSY} are not acceptable as long-term escapement goals, nor do they meet the standards for knowledge set by the Sustainable Salmon Fishery Policy.*" As author of this report and as a member of the ADF&G committee charged with developing biological escapement goals for the salmon stocks of AYK, I agree with these assessments. Further, I agree that the estimates of S_{MSY} should be used as short-term goals not as long-term goals due to uncertainty in many of the estimates used in the analyses. And, I agree that the S_{MSY} estimates should be revised as soon as possible taking into account new information as recommended in the draft reports themselves and in the Mundy et al. (2001) review document. Lastly, I agree that the standards for knowledge as discussed above are not fully met for any of the stocks described in the six draft ADF&G reports that were reviewed by Mundy et al. (2001). And until such time as a massive infusion of funding is made available for salmon stock assessment in the AYK region, this lack of basic information will unfortunately continue. I anticipate that approximately an order of magnitude of increase in funding would be needed to realistically address this problem.

Mundy et al. (2001) included several recommendations, including that a full detailed peer review of the six draft reports be undertaken and that all such reports be peer reviewed in the future. As authors, we have extended the review period for these reports by several months. No additional written comments beyond the two reviews discussed herein have been provided. These draft reports have been reviewed more than any other draft escapement goal reports developed by ADF&G to my knowledge. Mandatory scientific peer review of future ADF&G BEG reports would require a policy decision by ADF&G's leadership.

Mundy et al. (2001) recommended use of 90% confidence intervals as BEG ranges. I disagree. Doing so would put those stocks with the least reliable data at the most risk relative to the lower bound of the range due to the fact that more uncertainty (larger variance) is associated with those stocks with poorer information. I believe a range based on the estimated productivity, a method such as that developed by the Eggers (1993) approach used herein is a less risky approach. An adequate management range is thus defined and those stocks with poorer information are not unduly disenfranchised. Mundy et al. (2001) suggested incorporation of additional measurement error and simulation studies. I would agree if only such information existed. For instance, there is currently no technical means of estimating the variance associated with historic sonar passage estimates of Andreafsky chum salmon in 1981-1984; I know there is measurement error in those estimates, I simply have no way of estimating its magnitude. And, until better estimates complete with variances are made available for the basic data used in these stock-recruit analyses, it is my opinion that simulation studies will not be especially helpful, but rather will simply mirror the assumptions made in the simulation itself. Mundy et al. (2001) recommend that more precise harvest management capabilities be developed including better catch apportionment and escapement monitoring. I concur, however, again, it must be pointed out that a very large increase in funding for the salmon stock assessment program would be required to fully achieve this objective. Mundy et al. (2001) recommend that standard methods be developed for incorporation of error introduced throughout the process of preparing data for use in stock-recruitment analysis. Again I concur, but point out to achieve this objective would require a policy decision by ADF&G's leadership that in the salmon stock assessment program, variances be calculated in all cases where possible to accompany point estimates. Such a policy is in place in Sport Fish Division, but not in Commercial Fisheries Division at the current time. Mundy et al. (2001) recommend basic biological and physical data be substantially improved and that recommendations to improve the extent and quality of necessary data as identified in the draft reports be implemented. I concur. Mundy et al. (2001) recommends the expected performance of an escapement goal or range within the management plan be evaluated in view of critical uncertainties. I believe AYK BEG report authors have done so to the extent possible and my analyses concerning "Stock Status" in this report is intended to assist the reader in this regard.

Conclusions of the Mundy et al. (2001) review include the following: "*The eventual choices of escapement goals need to take account of how (1) natural variation, (2) inherent imprecision of estimates of catch and escapement, and (3) the circumstances where some harvest occurs no matter what the run size, interact to produce actual escapements. These three factors also interact with the requirements of the management plan and the capabilities of each harvest management program to influence the escapements that reach the spawning grounds each year. ... Bear in mind that "more is not necessarily better" when it comes to salmon escapement goals. Setting the goal far too high is not precautionary, because it could lead to lost production and smaller runs. Gathering quality data at all times, and relentless periodic evaluations are the surest means of adopting escapement goals that provide sustainable use for Alaska's salmon resources.*" I concur, and agree that gathering improved data concerning catches, escapements, age compositions, and stock compositions and that frequent scientific analysis of these stock-recruit data to identify appropriate escapement goals is the surest means of ADF&G fully achieving its constitutional mandate.

Mundy et al. (2001) includes comments that specifically address this Andreafsky River chum salmon report. The Mundy et al. (2001) review team clearly understood the data weaknesses associated with the Andreafsky River chum salmon stock and yet agreed the methods used in the analysis were "reasonably rigorous". The Mundy et al. (2001) review conclusion was "*Because of data weaknesses, the model is sufficient to use as a reference point in discussions regarding escapement goals, but should not be used as the sole criterion for escapement goal setting*". Mundy et al. (2001) goes on to say: "*Indications are that escapements may have been far too high to achieve maximum production which is possible if the problems in the stock and recruit data are discounted and data taken at face value. Relative to the conclusions of the Ricker framework analysis, the population is probably under-harvested. It would be useful to have auxiliary information on spawning densities. High spawning densities would corroborate the Ricker framework analyses. Apparent exploitation rates have been very low and recruit per spawner appears to be consistent with other chum populations.*" I concur with the review comments and as discussed earlier in this report, feel the escapement goal should be used only in the short term (next two years) and another analysis should be completed at that time based upon improved stock assessment data. Mundy et al. (2001) recommends additional data be collected as identified in the draft report as well as obtaining an understanding of "*freshwater survival drivers of mortalities as compared to marine drivers*". I concur, but point out to fully accomplish this recommendation concerning mortality drivers would require a substantial investment in the Andreafsky River chum salmon stock assessment program, beyond that presently existing, as well as an implementation of such a program for an extended period of time (more than 10 years).

Andersen et al. (2001) Review

Another review of the six draft ADF&G BEG reports entitled: "*Summary Review Comments*" was prepared by 12 staff from several federal agencies. Unlike Mundy et al. (2001), who largely accepted the BEGs proposed as being improvements over current goals, the federal review, hereafter referred to as Anderson et al. (2001), rejected them, writing that they had "little scientific merit". This comment on scientific merit notwithstanding, Anderson et al. (2001) concentrated on statistical, not scientific issues in the six draft reports. Some of these statistical issues were identified in Mundy et al. (2001) and in the reports themselves; the rest of the federal comments were largely invalid or were valid with little relevance. Anderson et al. (2001) was silent on alternatives to the current BEGs, even though these BEGs were based in most cases on little more than averages of the same data disparaged in Anderson et al. (2001). General comments by Anderson et al. (2001) follow along with my and other report authors responses.

Andersen et al. (2001) states: "*The importance of having precise estimates of escapements in a productivity analysis cannot be overestimated. If escapements are known with little error, uncertainty is limited to only one variable in the analysis, the harvest (return). If escapement estimates have moderate to high levels of variability, knowledge of both variables in the model is uncertain and confidence in the analysis is greatly reduced. Unfortunately, most of the subject analyses have incomplete records of total escapement, and these missing data must be estimated in order to reconstruct the entire runs.*" The first statement is overstated, the second true, the third sentence needs qualification, and the last is misleading. I won't comment further on the

first two sentences. As to the third, importance of measurement error is relative to the contrast in the estimates of escapements over the years (Hilborn and Walters 1992, p. 288-9). The larger the range of estimates, the less important their measurement error. It's largely on consideration of contrast that AYK BEG report authors recommended BEGs and Mundy et al. (2001) accepted the proposed BEGs. Authors of AYK BEG reports and Mundy et al. (2001) recognized that in cases with potentially great measurement error in estimated escapements, the contrast of escapements was sufficiently large to render a scientific judgement in support of the analyses. Anderson et al. (2001) comments on contrast only to say there is more than one kind without explaining what they mean. As to the final sentence, records were incomplete only for some of the stocks analyzed in the six draft reports, not for most of the stocks. Anvik River chum salmon escapements have been monitored with on-the grounds methodology each year since 1972. Full and complete historic escapement records were also available for the Chena River chinook salmon stock, the Salcha River chinook salmon stock, and the Kwiniuk River chum salmon stock. When measurement error information was available from the historic AYK database, it was quantified and shown not to be a problem and was reported as such.

Andersen et al. (2001) goes on to state: "*The authors commonly report "average percent errors" as a measure of uncertainty or variability associated with the estimation. This is not a reliable method of assessing variability, especially when the relationships are based upon small sample sizes. This method produces estimates of variability that are artificially small. At a minimum, cross-validation should be used (a model is built excluding a data point, and the model is then used to estimate that data point). Standard statistical methods of assessing the variance of predictions based on linear models could also be used.*" Uncertainty in estimates of escapement was reported as "average percent error" for some of the stocks analyzed. In the others, experience has shown that uncertainty should be negligible (i.e., chum salmon escapement in the Andreafsky River counted from a tower from 1986-1988 or by weir from 1994-present), or AYK BEG report authors have expressed uncertainty as estimated variances (i.e., chinook salmon in the Salcha and Chena rivers). Although I agree that "average percent error" is not the best measure of uncertainty in estimates of escapement, report authors left them as originally reported. We did so because cross-validation or predictions from linear models as proposed by Anderson et al. (2001) are flawed measures as well. The "right fix" would be to go back to the basic data (escapements, age compositions, harvest sampling efforts, etc.) and where possible, use sampling variances as estimated variances. The problem is that sampling variances were not reported or even calculated in most cases in the existing AYK database. Such statistics are currently readily available only for chinook salmon in the Salcha and Chena rivers. For many other stocks, information needed to calculate sampling variances has been lost or has never been collected. Some attempt to calculate historic sampling variances might be possible for some stocks (including the Andreafsky chum salmon stock), but would require considerably more time and effort than that available for these BEG analyses. In those cases, and in those where no calculations are possible at all, only subjective judgements are currently available as to the size of uncertainty in the estimated escapements.

Andersen et al. (2001) states: "*A weakness of most of the reports is that no attempt is made to assess how uncertainty in the estimation of missing escapement data might affect confidence in the estimates of the escapement producing maximum yield (S_{MSY}). The sensitivity of the estimates of S_{MSY} to the various assumptions used to estimate escapements should be explored through*

careful application of simulation techniques." The first sentence in this critique is misleading. Measurement error was assessed when that information was available from the historic database (as described above). Accuracy in estimates of S_{MSY} for the other stocks undoubtedly suffered to some degree from measurement error in estimates of escapement. But without sampling variances for estimated escapements, there is no objective way to measure the specific impact of measurement error on estimated S_{MSY}. As to the second sentence, simulation would show that the more uncertain we are in the data, the greater the negative bias in estimated S_{MSY}. Since this effect is well documented in the formal fishery science literature (see Hilborn and Walters 1992:290), we, as report authors, saw no need to confirm the effect again. Our response in the draft reports was to qualify those estimates of S_{MSY} that we believed might be biased low because of measurement error. Discussion of the estimated S_{MSY} for Norton Sound stocks typifies this approach. Note that the suggestion to simulate in Anderson et al. (2001) is not the same as the suggestion in Mundy et al. (2001). The former kind of simulation would have simulated variance for estimates of S_{MSY} as functions of estimated variances for estimated escapements. The simulation suggested by Mundy et al. (2001) would be a risk assessment for maintaining stock size as production is stochastically projected into the future. The former would be a statistical analysis while the latter would be a scientific investigation.

Andersen et al. (2001) criticized the bootstrapping approach used in the six draft reports for developing variances around estimates of S_{MSY}, pointing out that not every potential source of variation was accounted for in these bootstrap analyses. Such omissions would only be of concern if the potential sources of variation were something other than negligible. As described before, many sources of variation (measurement error) were likely negligible in their affect on estimated S_{MSY} (i.e., chum salmon counted by tower or weir in the Andreafsky River) or in estimates of harvest (i.e., chinook salmon in the Salcha and Chena rivers). In other cases, no estimates of variance were available. I believe that guessing at what they might be, would have been counter productive.

Andersen et al. (2001) criticized evaluation of residuals included in the six draft reports. This criticism is unfounded. Residuals are presented to the readers, and important information gleaned from residual analysis is fully addressed in the reports.

Andersen et al. (2001) takes issue of the concept of contrast as used in the six draft reports without fully describing what a better concept would be. The definition we used is implicitly given in Hilborn and Walters (1992:288) as the range of spawning escapements over the years (or their estimates) or the variance of spawning escapements over the years (or their estimates) (as implied in Quinn and Deriso 1999:108 taken from Fuller 1987). These definitions are standard within the research done of the affect of contrast on estimates of S_{MSY}.

Andersen et al. (2001) criticizes the AYK BEG report authors sometimes use of an approximation developed by Hilborn (1985) to estimate S_{MSY} instead of the usual "exact solution" derived by solving the first derivative of the estimated stock-recruit relationship through trial and error. This is a difference without a distinction. The expected difference in solutions from these two approaches would be in terms of tenths of a percent.

Andersen et al. (2001) was critical of situations where part of the time series of data was censored (e.g. chum salmon of the Kwiniuk and Tubutulik rivers). Data were censored because examination of residuals from the stock-recruit relationships estimated from the entire data series clearly showed that a significant change had occurred midway through the time series. Such a change implies that earlier productivity was not representative of later productivity. What the productivity in the immediate years ahead will be I do not know, but I believe that productivity in the next three years will be more like the last three years than the productivity estimated in the early years of the full time series. For this reason, I censored the earlier data and re-estimated the stock-recruit relationship. I realize that this is a scientifically subjective decision, but so too would it be to use the early data given the differential pattern of residuals.

Andersen et al. (2001) implied that recent large escapements producing poor returns are not indications of density dependence, but rather the result of reduced marine survival and criticized ADF&G analyses that fail to include factors other than escapement in the stock-recruit relationships. No estimates of the marine survival rates of smolts are available for any of the stocks in the draft reports. Without such information, no definitive scientific judgement on a marine cause behind poor returns is possible. Although reduced marine survival may have had an impact on salmon returns in recent years, there is evidence of poor returns from abundant spawners, not just in recent years, but in earlier years when spawners had been abundant. In contrast, fewer spawners produced better returns in many instances scattered throughout the years for many stocks. Such a relationship is the necessary condition consistent with density-dependent survival of young salmon. That there are several brood years represented along this spectrum, as is the case with stocks of chum salmon in Norton Sound, only strengthens the scientific judgements drawn.

The Andersen et al. (2001) review includes some comments that specifically address this Andreafsky River chum salmon report. Andersen et al. (2001) is critical of the July 14-26 timeframe used for selection of aerial survey data without giving a specific recommendation for an alternate time frame. They point out that 35% to 80% of observed spawned out fish were washed back on the weir on the dates I chose. The Andersen et al. (2001) review is silent on a suggested criterion to use and hence I am sticking with the originally selected timeframe for useable aerial surveys until a specific suggestion along with a valid scientific justification for improvement is made.

The Andersen et al. (2001) review states: *"Given the limitations of aerial survey data and the large variability associated with various expansions, the reconstructed escapements may not even provide reliable trend information."* . Although the Andersen et al. (2001) review team seriously disparages the usefulness of existing data from aerial surveys, they recommend not adopting new goals for the Andreafsky River chum salmon stocks, but sticking with old goals that are based on the same data from the aerial surveys minus those from recent years.

The Andersen et al. (2001) review is critical of the procedure I used to estimate harvest of the Andreafsky River chum salmon stock without giving suggestions for improvement and hence, I have no response. The Andersen et al. review is critical of the fact that I developed a suggested goal for the West Fork Andreafsky River to use as a replacement for the existing aerial survey escapement goal. They contend that a goal for the West Fork is not needed, the East Fork goal

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can be used to guide management. Perhaps this contention is true for managing fisheries inseason, although the truth of the point cannot be known without data from the West Fork. Even so, staff of ADF&G are required through our Escapement Goal Policy to establish escapement goals for all salmon stocks, not just those stocks that drive inseason management when returns are good.

As is obvious from reading the above passages, Anderson et al. (2001) often disparaged the quality of the data describing several of the stocks in the draft reports. While my view is not as pessimistic as theirs, I concede that the quality of the data describing some of the stocks could have been better. Limited funding has prevented ADF&G from adequately assessing harvest and escapements of salmon stocks in Western Alaska. Since then, circumstances have changed. With a new emphasis on the importance of stock assessment, the quality of future data should be greatly improved, and many of the statistical issues listed will be adequately addressed.

RECOMMENDATIONS

After full consideration of review comments, I recommend that the following biological escapement goals for the Andreafsky River stocks of summer chum salmon be formally adopted by the Alaska Department of Fish and Game.

East Fork of the Andreafsky River: 65,000 to 130,000 total spawners or 35,000 to 70,000 counted in an aerial survey.

West Fork of the Andreafsky River: 65,000 to 130,000 total spawners or 35,000 to 70,000 counted in an aerial survey.

I recommend that these biological escapement goals be sun-setted before the 2003 season and that a re-analysis of available data be conducted at that time to estimate appropriate biological escapement goals. I specifically recommend sun-setting to ensure that a re-analysis actually takes place in the hope that some of the uncertainty inherent in this report be technically addressed.

I recommend that the existing summer chum salmon stock assessment program for the Andreafsky River stocks be continued, advanced and improved upon. Changes I recommend:

1. Implement an on-the-grounds total escapement enumeration project for the West Fork chum salmon stock. These activities could take the form of a tower or weir program such as is currently operated on the East Fork or perhaps annual mark-recapture experiments. In any event, project goals should include the total enumeration or estimation of the West Fork chum salmon escapements complete with sampling variance on an annual basis based upon sampling information. Project goals should also include estimation of the annual age composition (and variances) of these escapements based upon active sampling efforts to capture, sample and age 300 to 500 chum salmon per year. Review the historic East Fork total chum salmon escapement estimates and calculate sampling variances. Similarly, update

the historic age composition database by calculating sampling variances and add all new information to the existing database.

2. Conduct aerial surveys of the East Fork chum salmon escapements between the dates of July 14 and 26 to gain additional expansion factor data points anticipating that additional data points will assist in historic run re-constructions. Conduct annual aerial surveys of the West Fork chum salmon escapements as was done in a fairly consistent fashion until 1994. The six year gap (1994-1999) in stock assessments for the West Fork of the Andreafsky is a major stumbling block to an understanding of the dynamics of the Andreafsky summer chum salmon stock.

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Table 1. Total abundance estimates and aerial surveys of summer chum salmon in the East Fork of the Andreafsky River, 1972-2000.

Year	Estimated Abundance of East Fork Chum Salmon	On the Grounds Total Estimate Method	East Fork Aerial Survey	Aerial Survey Rating and Observer Initials	Date of Aerial Survey	Comments Associated with Aerial Survey	Percent of Total Observed During Survey
1972	-	none	41,460	2-RR	22-Jul	-	-
1973	-	none	10,149	3-HG	27-Jul	Incomplete and late	-
1974	-	none	3,215	?-HG	04-Jul	Survey was early	-
1975	-	none	223,485	2-RR	22-Jul	-	-
1976	-	none	105,347	2-RR	16-Jul	-	-
1977	-	none	112,722	1-HG	20-Jul	-	-
1978	-	none	127,050	2-BA	11-Jul	Survey was early	-
1979	-	none	66,471	2-RR	16-Jul	lower10-15 miles turbid	-
1980	-	none	36,823	3-HG	23-Jul	Turbulence	-
1981	147,312	sonar	81,555	2-RR	23-Jul	-	**55.4%**
1982	181,352	sonar	7,501	3-JB	20-Jul	-	*4.1%*
1983	110,608	sonar	None			-	-
1984	70,125	sonar	95,200	3-RR	13-Jul	Early & upper 1/3 turbid	*135.8%*
1985	-	none	66,146	1-RR	23-Jul	-	
1986	167,614	tower	83,931	2-DB	14-Jul	Chum-pink confusion	**50.1%**
1987	45,221	tower	6,687	1-CW	27-Jul	Late for chums	*14.8%*
1988	68,937	tower	43,056	1-K	16-Jul	-	**62.5%**
1989	-	none	21,460	3-RB	03-Jul	Early, King-chum conf.	-
1990	-	none	11,519	3-DB	12-Jul	Early & partial survey	-
1991	-	none	31,886	2-B	22-Jul	-	-
1992	-	none	11,308	3-B	17-Jul	Numerous pinks	-
1993	-	none	10,935	1-B	11-Jul	Early survey	-
1994	200,981	weir	none				
1995	172,148	weir	none				
1996	108,450	weir	none				
1997	51,139	weir	none				
1998	67,591	weir	none				
1999	32,229	weir	none				
2000	23,349	weir	2,094	2-TL	29-Jul	Late for chums	*9.0%*
Avg.							**56.0%**

Note: Survey dates prior to July 14 were considered early and dates after July 26 were considered late. Only surveys with a rating of 1 (good) or 2 (fair) and within the dates of July 14-26 were used for estimating the average percent of the total escapement observed during a survey (the three values used for estimating this average are shown in **bold**). Survey and total abundance data was from three sources: Bergstrom et al (1999), Sandone (1994) and Lingnau (ADF&G, Anchorage, personal communication).

Table 2. Estimated average percent errors associated with the use of the average 56% aerial survey expansion factor methodology that was used to estimate some of the total escapement estimates for chum salmon in the East and West Forks of the Andreafsky River.

Year	Estimated Abundance of East Fork Chum Salmon	East Fork Aerial Survey	Percent of Total Observed During Survey	Predicted Abundance of East Fork Chum Salmon	Observed Minus Predicted (Absolute Difference)	Average Percent Error
1981	147,312	81,555	55.4%	145,727	1,585	1%
1986	167,614	83,931	50.1%	149,972	17,642	11%
1988	68,937	43,056	62.5%	76,935	7,998	12%
Average					9,075	8%

Table 3. Total abundance estimates for summer chum salmon in the East Fork of the Andreafsky River based upon on-the-grounds estimation procedures or based upon the 56.0% average expansion factor procedure.

Year	Observed Abundance of East Fork Chum Salmon	On the Grounds Total Estimate Method	East Fork Aerial Survey	Aerial Survey Rating and Observer Initials	Date of Aerial Survey	Estimated Total Abundance of East Fork Chum Salmon	Total Abundance Estimation Method
1972	-	none	41,460	2-RR	22-Jul	74,083	56.0% Avg
1973	-	none	10,149	3-HG	27-Jul		
1974	-	none	3,215	?-HG	04-Jul		
1975	-	none	223,485	2-RR	22-Jul	399,334	56.0% Avg
1976	-	none	105,347	2-RR	16-Jul	188,239	56.0% Avg
1977	-	none	112,722	1-HG	20-Jul	201,417	56.0% Avg
1978	-	none	127,050	2-BA	11-Jul		
1979	-	none	66,471	2-RR	16-Jul	118,774	56.0% Avg
1980	-	none	36,823	3-HG	23-Jul		
1981	147,312	sonar	81,555	2-RR	23-Jul	147,312	Sonar
1982	181,352	sonar	7,501	3-JB	20-Jul	181,352	Sonar
1983	110,608	sonar	None			110,608	Sonar
1984	70,125	sonar	95,200	3-RR	13-Jul	70,125	Sonar
1985	-	none	66,146	1-RR	23-Jul	118,193	56.0% Avg
1986	167,614	tower	83,931	2-DB	14-Jul	167,614	Tower
1987	45,221	tower	6,687	1-CW	27-Jul	45,221	Tower
1988	68,937	tower	43,056	1-K	16-Jul	68,937	Tower
1989	-	none	21,460	3-RB	03-Jul		
1990	-	none	11,519	3-DB	12-Jul		
1991	-	none	31,886	2-B	22-Jul	56,976	56.0% Avg
1992	-	none	11,308	3-B	17-Jul		
1993	-	none	10,935	1-B	11-Jul		
1994	200,981	weir	none			200,981	weir
1995	172,148	weir	none			172,148	weir
1996	108,450	weir	none			108,450	weir
1997	51,139	weir	none			51,139	weir
1998	67,591	weir	none			67,591	weir
1999	32,229	weir	none			32,229	weir
2000	23,349	weir	2,094	2-TL	29-Jul	23,349	weir

Note: Only surveys with a rating of 1 (good) or 2 (fair) and within the dates of July 14-26 were used in combination with the average expansion factor of 56.0% for estimating total escapements).

Table 4. Total abundance estimates for summer chum salmon in the West Fork of the Andreafsky River based upon the 56.0% average expansion factor procedure.

Year	West Fork Aerial Survey	Aerial Survey Rating and Observer Initials	Date of Aerial Survey	Comments Associated with Aerial Survey	Estimated Total Abundance of West Fork Chum Salmon
1972	25,573	3-HG	26-Jul	-	
1973	51,835	2-RR	21-Jul	-	92,621
1974	33,578	2-LT	14-Jul	-	59,999
1975	235,954	1-RR	22-Jul	-	421,615
1976	118,420	2-RR	16-Jul	-	211,599
1977	63,120	1-HG	20-Jul	-	112,786
1978	57,321	2-HG	14-Jul	-	102,424
1979	43,391	2-HG	18-Jul	Lower 20 miles were turbid	77,533
1980	114,759	2-HG	23-Jul	Turbulence	205,057
1981	None	-	-	-	
1982	7,267	3-JB	20-Jul	Under-counted due to pinks	
1983	None	-	-	-	
1984	238,565	1-RR	13-Jul	Early for chums	
1985	52,750	2-RR	23-Jul	-	94,256
1986	99,373	1-DB	14-Jul	-	177,565
1987	35,535	1-DB	26-Jul	Including Allen Cr. (3,537)	63,496
1988	45,432	2-K	16-Jul	-	81,180
1989	none	-	-	-	
1990	20,426	3-DB	12-Jul	Partial count and early	
1991	46,657	2-B	22-Jul	-	83,369
1992	37,808	3-B	22-Jul	Numerous pinks	
1993	9,111	1-B	11-Jul	Early for chums	
1994					
1995					
1996					
1997					
1998					
1999					
2000	18,989	1-TL	29-Jul	Late for chums	

Note: Only surveys with a rating of 1 (good) or 2 (fair) and within the dates of July 14-26 were used in combination with the average expansion factor of 56.0% for estimating total escapements. This methodology assumes the average percent observed for the East Fork population of chum salmon is applicable to West Fork surveys given they are rated as 1 or 2 and they occurred within the 13 day period of July 14-26. Survey data was from three sources: Bergstrom et al (1999), Sandone (1994) and Lingnau (ADF&G, Anchorage, personal communication).

Table 5. Paired total abundance estimates for summer chum salmon in the East and West Forks of the Andreafsky River based upon on-the-grounds estimation procedures or upon the 56.0% average expansion factor methodology.

Year	East Fork Andreafsky Total Chum Salmon Estimate	West Fork Andreafsky Total Chum Salmon Estimate
1975	399,334	421,615
1976	188,239	211,599
1977	201,417	112,786
1979	118,774	77,533
1985	118,193	94,256
1986	167,614	177,565
1987	45,221	63,496
1988	68,937	81,180
1991	56,976	83,369
Averages	151,634	147,044

Note: These two total abundance data sets are significantly correlated (correlation = 0.9397, significant at the 0.005 level). Regression of the two data sets with an intercept of 0 resulted in a relationship that was significant at the 0.00011 level, adjusted r squared = 0.758, and slope = 0.9753. This regression approach to estimating total escapements is called the East-West regression in later tables.

Table 6. Estimated average percent errors associated with the use of the East-West regression procedure that was used to develop some of the total abundance estimates for the East and West Forks of the Andreafsky River chum salmon spawning populations.

Year	East Fork Total Chum Salmon Estimate	West Fork Total Chum Salmon Estimate	East Fork Total Chum Salmon Predicted Estimate	West Fork Total Chum Salmon Predicted Estimate	East Fork Estimated Minus Predicted (Absolute Value)	East Fork Percent Error	West Fork Estimated Minus Predicted (Absolute Value)	West Fork Percent Error
1975	399,334	421,615	432,279	389,483	32,945	8%	32,132	8%
1976	188,239	211,599	216,951	183,595	28,712	15%	28,004	13%
1977	201,417	112,786	115,639	196,448	85,779	43%	83,662	74%
1979	118,774	77,533	79,494	115,844	39,279	33%	38,310	49%
1985	118,193	94,256	96,641	115,277	21,552	18%	21,021	22%
1986	167,614	177,565	182,056	163,479	14,442	9%	14,086	8%
1987	45,221	63,496	65,102	44,105	19,881	44%	19,390	31%
1988	68,937	81,180	83,234	67,236	14,297	21%	13,944	17%
1991	56,976	83,369	85,478	55,570	28,502	50%	27,799	33%
Avg	151,634	147,044			31,710	27%	30,928	28%

Table 9. Total escapement estimates for summer chum salmon in the Andreafsky and Anvik Rivers in years when the Andreafsky estimates are based upon on-the-grounds estimation procedures, upon the 56.0% average expansion factor procedure or based upon the East-West regression procedure.

Year	East Fork Total Escapement Estimate	West Fork Total Escapement Estimate	Combined Total Escapement Estimate	Anvik Total Escapement Estimate
1981	147,312	143,678	290,990	1,486,182
1982	181,352	176,878	358,230	444,581
1983	110,608	107,879	218,487	362,912
1984	70,125	68,395	138,520	891,028
1985	118,193	94,256	212,449	1,080,243
1986	167,614	177,565	345,179	1,189,602
1987	45,221	63,496	108,717	455,876
1988	68,937	81,180	150,117	1,125,449
1991	56,976	83,369	140,345	847,772
1994	200,981	196,023	397,004	1,124,689
1995	172,148	167,901	340,049	1,339,418
1996	108,450	105,774	214,224	933,240
1997	51,139	49,877	101,016	609,118
1998	67,591	65,923	133,514	471,885
1999	32,229	31,434	63,663	437,631
2000	23,349	22,773	46,122	205,460

Note: The Andreafsky and Anvik River total escapement data sets are significantly correlated (correlation = 0.58963825, significant at the 0.01 level). Regression of the two data sets with an intercept of 0 resulted in a relationship that was significant at the 0.0298 level, adjusted r squared = 0.214, and slope = 0.23598245.

Table 10. Estimated average percent errors associated with the use of the summed Andreafsky-Anvik River regression procedure that was used to develop four of the total annual abundance estimates for the Andreafsky River chum salmon spawning population.

Year	Andreafsky Summed Escapement Estimates	Anvik Estimated Total Escapements	Predicted Andreafsky Summed Escapements	Observed Estimate Minus Predicted (Absolute Value)	Percent Error
1981	290,990	1,486,182	350,713	59,723	21%
1982	358,230	444,581	104,913	253,317	71%
1983	218,487	362,912	85,641	132,846	61%
1984	138,520	891,028	210,267	71,747	52%
1985	212,449	1,080,243	254,918	42,469	20%
1986	345,179	1,189,602	280,725	64,454	19%
1987	108,717	455,876	107,579	1,138	1%
1988	150,117	1,125,449	265,586	115,469	77%
1991	140,345	847,772	200,059	59,715	43%
1994	397,004	1,124,689	265,407	131,597	33%
1995	340,049	1,339,418	316,079	23,970	7%
1996	214,224	933,240	220,228	6,004	3%
1997	101,016	609,118	143,741	42,725	42%
1998	133,514	471,885	111,357	22,158	17%
1999	63,663	437,631	103,273	39,610	62%
2000	46,122	205,460	48,485	2,363	5%
Averages	**203,664**	**812,818**	**191,811**	**66,831**	**33%**

Table 11. Total abundance estimates for summer chum salmon in the East Fork of the Andreafsky River based upon on-the-grounds estimation procedures, based upon the 56.0% average expansion factor procedure, based upon the East-West regression procedure, or based upon the summed Andreafsky-Anvik regression procedure.

Year	Observed Abundance of East Fork Chum Salmon	On the Grounds Total Estimate Method	East Fork Aerial Survey	Aerial Survey Rating and Observer Initials	Date of Aerial Survey	Estimated Total Abundance of East Fork Chum Salmon	Total Abundance Estimation Method
1972	-	none	41,460	2-RR	22-Jul	74,083	56.0% Avg
1973	-	none	10,149	3-HG	27-Jul	94,964	E-W Reg.
1974	-	none	3,215	?-HG	04-Jul	61,517	E-W Reg.
1975	-	none	223,485	2-RR	22-Jul	399,334	56.0% Avg
1976	-	none	105,347	2-RR	16-Jul	188,239	56.0% Avg
1977	-	none	112,722	1-HG	20-Jul	201,417	56.0% Avg
1978	-	none	127,050	2-BA	11-Jul	105,015	E-W Reg.
1979	-	none	66,471	2-RR	16-Jul	118,774	56.0% Avg
1980	-	none	36,823	3-HG	23-Jul	210,244	E-W Reg.
1981	147,312	sonar	81,555	2-RR	23-Jul	147,312	Sonar
1982	181,352	sonar	7,501	3-JB	20-Jul	181,352	Sonar
1983	110,608	sonar	None			110,608	Sonar
1984	70,125	sonar	95,200	3-RR	13-Jul	70,125	Sonar
1985	-	none	66,146	1-RR	23-Jul	118,193	56.0% Avg
1986	167,614	tower	83,931	2-DB	14-Jul	167,614	Tower
1987	45,221	tower	6,687	1-CW	27-Jul	45,221	Tower
1988	68,937	tower	43,056	1-K	16-Jul	68,937	Tower
1989	-	none	21,460	3-RB	03-Jul	76,051	A-A Reg.
1990	-	none	11,519	3-DB	12-Jul	48,196	A-A Reg.
1991	-	none	31,886	2-B	22-Jul	56,976	56.0% Avg
1992	-	none	11,308	3-B	17-Jul	92,615	A-A Reg.
1993	-	none	10,935	1-B	11-Jul	61,782	A-A Reg.
1994	200,981	weir	none			200,981	Weir
1995	172,148	weir	none			172,148	Weir
1996	108,450	weir	none			108,450	Weir
1997	51,139	weir	none			51,139	Weir
1998	67,591	weir	none			67,591	Weir
1999	32,229	weir	none			32,229	Weir
2000	23,349	weir	2,094	2-TL	29-Jul	23,349	Weir

Note: Only surveys with a rating of 1 (good) or 2 (fair) and within the dates of July 14-26 were used in combination with the average expansion factor of 56.0% for estimating total escapements. East Fork regression estimates only occurred in cases where a total escapement estimate was available for the West Fork; in those cases the East Fork estimate was calculated as the West Fork total estimate/0.9753293. Summed Andreafsky-Anvik regression estimates were used for 1989, 1990, 1992, and 1993 when other estimation procedures for the Andreafsky escapements could not be used. Methodology was summed Andreafsky = 0.23598245 * Anvik estimated total escapement. The summed Andreafsky escapement was split between the East and West Forks by taking the summed estimate and multiplying it by 0.506 for the East Fork estimate and by 0.494 for the West Fork estimate.

Table 12. Total abundance estimates for summer chum salmon in the West Fork of the Andreafsky River based upon the 56.0% average expansion factor procedure, based upon the East-West regression procedure, or based upon the summed Andreafsky-Anvik regression procedure.

Year	West Fork Aerial Survey	Aerial Survey Rating and Observer Initials	Date of Aerial Survey	Estimated Total Abundance of West Fork Chum Salmon	Total Abundance Estimation Method
1972	25,573	3-HG	26-Jul	72,255	E-W Regression
1973	51,835	2-RR	21-Jul	92,621	56.0% Average
1974	33,578	2-LT	14-Jul	59,999	56.0% Average
1975	235,954	1-RR	22-Jul	421,615	56.0% Average
1976	118,420	2-RR	16-Jul	211,599	56.0% Average
1977	63,120	1-HG	20-Jul	112,786	56.0% Average
1978	57,321	2-HG	14-Jul	102,424	56.0% Average
1979	43,391	2-HG	18-Jul	77,533	56.0% Average
1980	114,759	2-HG	23-Jul	205,057	56.0% Average
1981	None	-	-	143,678	E-W Regression
1982	7,267	3-JB	20-Jul	176,878	E-W Regression
1983	None	-	-	107,879	E-W Regression
1984	238,565	1-RR	13-Jul	68,395	E-W Regression
1985	52,750	2-RR	23-Jul	94,256	56.0% Average
1986	99,373	1-DB	14-Jul	177,565	56.0% Average
1987	35,535	1-DB	26-Jul	63,496	56.0% Average
1988	45,432	2-K	16-Jul	81,180	56.0% Average
1989	none	-	-	74,248	A-A Regression
1990	20,426	3-DB	12-Jul	47,053	A-A Regression
1991	46,657	2-B	22-Jul	83,369	56.0% Average
1992	37,808	3-B	22-Jul	90,419	A-A Regression
1993	9,111	1-B	11-Jul	60,317	A-A Regression
1994				196,023	E-W Regression
1995				167,901	E-W Regression
1996				105,774	E-W Regression
1997				49,877	E-W Regression
1998				65,923	E-W Regression
1999				31,434	E-W Regression
2000	18,989	1-TL	29-Jul	22,773	E-W Regression

Note: Only surveys with a rating of 1 (good) or 2 (fair) and within the dates of July 14-26 were used in combination with the average expansion factor of 56.0% for estimating total escapements. This methodology assumes the average percent observed for the East Fork population of chum salmon is applicable to West Fork surveys given they are rated as 1 or 2 and they occurred within the 13 day period of July 14-26. West Fork regression estimates only occurred in cases where a total escapement estimate was available for the East Fork; in those cases the West Fork estimate was calculated as the East Fork total estimate * 0.9753293. Summed Andreafsky-Anvik regression estimates were used for 1989, 1990, 1992, and 1993 when other estimation procedures for the Andreafsky escapements could not be used. Methodology was summed Andreafsky = 0.23598245 * Anvik estimated total escapement. The summed Andreafsky escapement was split between the East and West Forks by taking the summed estimate and multiplying it by 0.506 for the East Fork estimate and by 0.494 for the West Fork estimate.

Table 13. Anvik River chum salmon escapements, in-river runs of Anvik River chum salmon, and chum salmon total utilization in Districts 1-4 of the Yukon River, 1972-2000.

Year	Anvik Chum Escapement	Anvik In-River Harvests	Anvik In-River Run	Y1 Total Harvest	Y2 Total Harvest	Y3 Total Harvest	Y4 Total Harvest
1972	457,800	-	457,800	127,893	34,630	5,239	57,745
1973	249,015	-	249,015	242,007	83,859	7,487	86,085
1974	411,133	-	411,133	494,814	103,097	11,659	149,665
1975	900,967	-	900,967	445,120	126,060	9,243	278,339
1976	511,475	-	511,475	296,837	122,933	17,954	311,218
1977	358,771	-	358,771	270,824	125,945	10,370	254,818
1978	307,270	-	307,270	424682	249,232	28,709	474,243
1979	280,537	-	280,537	386,078	196,114	49,546	286,585
1980	492,676	-	492,676	407,224	322,385	50,509	400,689
1981	1,486,182	-	1,486,182	518,468	366,096	61,901	378,897
1982	444,581	-	444,581	267,968	200,786	9,926	315,686
1983	362,912	-	362,912	475,843	275,488	19,209	302,101
1984	891,028	-	891,028	321,135	263,927	8,438	327,300
1985	1,080,243	-	1,080,243	271,835	207,894	5,479	487,322
1986	1,189,602	-	1,189,602	419,981	329,923	12,680	518,555
1987	455,876	-	455,876	253,658	208,010	15,677	258,711
1988	1,125,449	-	1,125,449	677,548	453,959	28,574	576,697
1989	636,906	-	636,906	601,006	383,665	20,402	551,179
1990	403,627	-	403,627	186,166	160,960	10,164	249,084
1991	847,772	-	847,772	169,633	196,555	14,457	344,913
1992	775,626	-	775,626	212,486	171,860	9,664	247,208
1993	517,409	-	517,409	109,323	45,239	8,022	63,033
1994	1,124,689	22,573	1,147,262	89,854	41,964	8,586	176,522
1995	1,339,418	54,744	1,394,162	182,928	111,408	12,143	524,927
1996	933,240	84,633	1,017,873	127,104	59,153	12,902	442,032
1997	609,118	13,548	622,666	89,720	45,246	10,316	135,353
1998	471,885	-	471,885	51,093	33,212	6,472	18,046
1999	437,631	-	437,631	36,350	30,680	944	11,336
2000	205,460	-	205,460	23,000	18,309	1,000	10,000

Data sources: Annual Management Report for the Yukon River, 1998 (Bergstrom et al 1999) for the years 1972-1998; escapement data taken from page 204 and harvest related data taken from page 105 and 106. Because subsistence catches for the years 1972-1977 were not directly estimated and reported by district, the average district specific distribution from 1978-1982 was assumed and used to develop district specific estimates for the first six years of the data set. Data for the years 1999 and 2000 provided by Thomas Vania (ADF&G, Anchorage, personal communication). Because subsistence harvests in 2000 were not yet available, 2000 subsistence harvests were assumed to be about the same as 1999 harvests.

Table 14. Estimated annual Anvik River origin chum salmon runs, 1972-2000. Harvests in Districts 1, 2, and 3 assumed to be 50% Anvik origin and harvest in District 4 assumed to be 15% Anvik origin (Clark and Sandone 2001).

Year	Anvik In-River Estimated Return	Anvik Origin Harvest in Y1	Anvik Origin Harvest in Y2	Anvik Origin Harvest in Y3	Anvik Origin Harvest in Y4	Estimated Total Runs of Anvik Origin Chums
1972	457,800	63,947	17,315	2,619	8,662	550,342
1973	249,015	121,003	41,930	3,743	12,913	428,604
1974	411,133	247,407	51,548	5,829	22,450	738,368
1975	900,967	222,560	63,030	4,622	41,751	1,232,930
1976	511,475	148,418	61,467	8,977	46,683	777,020
1977	358,771	135,412	62,972	5,185	38,223	600,563
1978	307,270	212,341	124,616	14,355	71,136	729,718
1979	280,537	193,039	98,057	24,773	42,988	639,394
1980	492,676	203,612	161,193	25,255	60,103	942,838
1981	1,486,182	259,234	183,048	30,951	56,835	2,016,249
1982	444,581	133,984	100,393	4,963	47,353	731,274
1983	362,912	237,922	137,744	9,605	45,315	793,497
1984	891,028	160,568	131,964	4,219	49,095	1,236,873
1985	1,080,243	135,918	103,947	2,740	73,098	1,395,945
1986	1,189,602	209,991	164,962	6,340	77,783	1,648,677
1987	455,876	126,829	104,005	7,839	38,807	733,355
1988	1,125,449	338,774	226,980	14,287	86,505	1,791,994
1989	636,906	300,503	191,833	10,201	82,677	1,222,119
1990	403,627	93,083	80,480	5,082	37,363	619,635
1991	847,772	84,817	98,278	7,229	51,737	1,089,831
1992	775,626	106,243	85,930	4,832	37,081	1,009,712
1993	517,409	54,662	22,620	4,011	9,455	608,156
1994	1,147,262	44,927	20,982	4,293	26,478	1,243,942
1995	1,394,162	91,464	55,704	6,072	78,739	1,626,141
1996	1,017,873	63,552	29,577	6,451	66,305	1,183,757
1997	622,666	44,860	22,623	5,158	20,303	715,610
1998	471,885	25,547	16,606	3,236	2,707	519,980
1999	437,631	18,175	15,340	472	1,700	473,318
2000	205,460	11,500	9,155	500	1,500	228,115

Table 15. Estimated annual Anvik River origin chum salmon exploitation rates in Districts 1, 2, 3, and 4 of the Yukon River.

Year	Estimated Anvik Origin Exploit. In Y1	Estimated Anvik Origin Exploit. In Y2	Estimated Anvik Origin Exploit. In Y3	Estimated Anvik Origin Exploit. In Y4	Estimated Anvik Origin Exploit. In Anvik Portion of Y4	Estimated Anvik Origin Exploit. In All of Y4	Estimated Anvik Origin Exploit. In Total
1972	11.6%	3.1%	0.5%	1.6%	0.0%	1.6%	16.8%
1973	28.2%	9.8%	0.9%	3.0%	0.0%	3.0%	41.9%
1974	33.5%	7.0%	0.8%	3.0%	0.0%	3.0%	44.3%
1975	18.1%	5.1%	0.4%	3.4%	0.0%	3.4%	26.9%
1976	19.1%	7.9%	1.2%	6.0%	0.0%	6.0%	34.2%
1977	22.5%	10.5%	0.9%	6.4%	0.0%	6.4%	40.3%
1978	29.1%	17.1%	2.0%	9.7%	0.0%	9.7%	57.9%
1979	30.2%	15.3%	3.9%	6.7%	0.0%	6.7%	56.1%
1980	21.6%	17.1%	2.7%	6.4%	0.0%	6.4%	47.7%
1981	12.9%	9.1%	1.5%	2.8%	0.0%	2.8%	26.3%
1982	18.3%	13.7%	0.7%	6.5%	0.0%	6.5%	39.2%
1983	30.0%	17.4%	1.2%	5.7%	0.0%	5.7%	54.3%
1984	13.0%	10.7%	0.3%	4.0%	0.0%	4.0%	28.0%
1985	9.7%	7.4%	0.2%	5.2%	0.0%	5.2%	22.6%
1986	12.7%	10.0%	0.4%	4.7%	0.0%	4.7%	27.8%
1987	17.3%	14.2%	1.1%	5.3%	0.0%	5.3%	37.8%
1988	18.9%	12.7%	0.8%	4.8%	0.0%	4.8%	37.2%
1989	24.6%	15.7%	0.8%	6.8%	0.0%	6.8%	47.9%
1990	15.0%	13.0%	0.8%	6.0%	0.0%	6.0%	34.9%
1991	7.8%	9.0%	0.7%	4.7%	0.0%	4.7%	22.2%
1992	10.5%	8.5%	0.5%	3.7%	0.0%	3.7%	23.2%
1993	9.0%	3.7%	0.7%	1.6%	0.0%	1.6%	14.9%
1994	3.6%	1.7%	0.3%	2.1%	1.8%	3.9%	9.6%
1995	5.6%	3.4%	0.4%	4.8%	3.4%	8.2%	17.6%
1996	5.4%	2.5%	0.5%	5.6%	7.1%	12.8%	21.2%
1997	6.3%	3.2%	0.7%	2.8%	1.9%	4.7%	14.9%
1998	4.9%	3.2%	0.6%	0.5%	0.0%	0.5%	9.2%
1999	3.8%	3.2%	0.1%	0.4%	0.0%	0.4%	7.5%
2000	5.0%	4.0%	0.2%	0.7%	0.0%	0.7%	9.9%

Table 16. Estimated annual Andreafsky River origin chum salmon exploitation rates in Districts 1 and 2 of the Yukon River.

Year	Estimated Exploitation of Andreafsky Origin Chum Salmon In Y1	Portion of District Y2 Catch Below Mouth of Andreafsky River	Estimated Exploitation of Andreafsky Origin Chum Salmon In Y2	Estimated Total Exploitation of Andreafsky Origin Chum Salmon In the Yukon
1972	11.6%	59.1%	1.9%	13.5%
1973	28.2%	59.1%	5.8%	34.0%
1974	33.5%	59.1%	4.1%	37.6%
1975	18.1%	59.1%	3.0%	21.1%
1976	19.1%	59.1%	4.7%	23.8%
1977	22.5%	59.1%	6.2%	28.7%
1978	29.1%	59.1%	10.1%	39.2%
1979	30.2%	59.1%	9.1%	39.3%
1980	21.6%	59.1%	10.1%	31.7%
1981	12.9%	59.1%	5.4%	18.2%
1982	18.3%	59.1%	8.1%	26.4%
1983	30.0%	52.2%	9.1%	39.0%
1984	13.0%	58.3%	6.2%	19.2%
1985	9.7%	64.1%	4.8%	14.5%
1986	12.7%	60.3%	6.0%	18.8%
1987	17.3%	59.0%	8.4%	25.7%
1988	18.9%	50.5%	6.4%	25.3%
1989	24.6%	54.3%	8.5%	33.1%
1990	15.0%	40.0%	5.2%	20.2%
1991	7.8%	66.6%	6.0%	13.8%
1992	10.5%	61.8%	5.3%	15.8%
1993	9.0%	47.4%	1.8%	10.7%
1994	3.6%	73.2%	1.2%	4.8%
1995	5.6%	74.7%	2.6%	8.2%
1996	5.4%	72.4%	1.8%	7.2%
1997	6.3%	82.6%	2.6%	8.9%
1998	4.9%	44.7%	1.4%	6.3%
1999	3.8%	43.0%	1.4%	5.2%
2000	5.0%	59.1%	2.4%	7.4%

Note: Portion of District Y2 catch below mouth of Andreafsky River estimated based on catches in Subdistricts 334-21 and 334-22 in the years 1983-1999. Annual values for the years 1972-1982 and 2000 are based on the average value obtained for the years 1983-1999.

Table 17. Estimated annual Andreafsky River origin chum salmon escapements, catches, total runs, and total exploitation rates, 1972-2000.

Year	Estimated Total Andreafsky Escapements (East & West Forks)	Estimated Andreafsky Origin Chum Salmon Catches	Estimated Andreafsky Origin Total Runs of Chum Salmon	Estimated Exploitation Rate of Andreafsky Origin Chum Salmon
1972	146,338	22,798	169,136	13%
1973	187,586	96,695	284,281	34%
1974	121,515	73,326	194,841	38%
1975	820,949	219,186	1,040,135	21%
1976	399,838	124,722	524,560	24%
1977	314,204	126,752	440,956	29%
1978	207,439	133,701	341,140	39%
1979	196,307	126,859	323,167	39%
1980	415,301	192,757	608,058	32%
1981	290,990	64,844	355,834	18%
1982	358,230	128,735	486,965	26%
1983	218,487	139,979	358,466	39%
1984	138,520	32,912	171,432	19%
1985	212,449	36,061	248,510	15%
1986	345,179	79,770	424,949	19%
1987	108,717	37,532	146,249	26%
1988	150,117	50,833	200,950	25%
1989	150,299	74,407	224,706	33%
1990	95,249	24,136	119,385	20%
1991	140,345	22,438	162,783	14%
1992	183,034	34,288	217,322	16%
1993	122,099	14,706	136,805	11%
1994	397,004	20,217	417,220	5%
1995	340,049	30,307	370,356	8%
1996	214,224	16,562	230,787	7%
1997	101,016	9,844	110,860	9%
1998	133,514	9,038	142,552	6%
1999	63,663	3,515	67,178	5%
2000	46,122	3,693	49,815	7%
Average	**228,234**	**67,262**	**295,496**	**21%**
Minimum	**46,122**	**3,515**	**49,815**	**5%**
Maximum	**820,949**	**219,186**	**1,040,135**	**39%**

Table 18. Age composition of summer chum salmon sampled from the East Fork Andreafsky River escapements, 1972-2000.

Year	Number of Chum Salmon Sampled and Aged	Percent Age 3	Percent Age 4	Percent Age 5	Percent Age 6	Total
1972	None	0.9	55.5	41.0	2.6	100.0
1973	None	0.9	55.5	41.0	2.6	100.0
1974	None	0.9	55.5	41.0	2.6	100.0
1975	None	0.9	55.5	41.0	2.6	100.0
1976	None	0.9	55.5	41.0	2.6	100.0
1977	None	0.9	55.5	41.0	2.6	100.0
1978	None	0.9	55.5	41.0	2.6	100.0
1979	None	0.9	55.5	41.0	2.6	100.0
1980	None	0.9	55.5	41.0	2.6	100.0
1981	None	0.9	55.5	41.0	2.6	100.0
1982	461	2.4	72.9	23.2	1.5	100.0
1983	834	0.6	37.3	60.8	1.3	100.0
1984	451	4.0	69.6	24.4	2.0	100.0
1985	566	1.9	71.9	26.0	0.2	100.0
1986	775	0.3	60.9	37.2	1.7	100.0
1987	362	0.8	28.7	66.6	3.9	100.0
1988	525	1.3	69.9	25.7	3.1	100.0
1989	135	2.2	45.2	51.1	1.5	100.0
1990	227	1.1	92.6	6.3	0.0	100.0
1991	128	0.0	51.6	46.9	1.6	100.0
1992	69	0.0	24.6	66.7	8.7	100.0
1993	373	0.5	59.8	37.5	2.1	100.0
1994	733	0.0	68.9	30.0	1.1	100.0
1995	833	0.7	44.8	52.1	2.4	100.0
1996	1,277	0.5	58.1	35.4	6.0	100.0
1997	1,403	0.0	27.6	66.6	5.8	100.0
1998	830	0.4	83.4	14.5	1.8	100.0
1999	839	1.2	26.9	69.2	2.6	100.0
2000	629	0.2	59.0	37.8	3.0	100.0
Average	**603**	**0.9**	**55.5**	**41.0**	**2.6**	**100.0**
Minimum	**69**	**0.0**	**24.6**	**6.3**	**0.0**	**100.0**
Maximum	**1,403**	**4.0**	**92.6**	**69.2**	**8.7**	**100.0**

Data source: East Fork Andreafsky River age composition estimates for summer chum salmon provided to author by Tracy Lingnau (ADF&G, Anchorage, personal communication). Average values used for the years 1972-1981.

Table 19. Age composition of summer chum salmon sampled from Yukon River catches, 1972-2000.

Year	Number of Chum Salmon Sampled and Aged	Percent Age 3	Percent Age 4	Percent Age 5	Percent Age 6	Total
1972	224	6.5	52.0	41.5	-	100.0
1973	223	5.8	63.7	29.6	0.9	100.0
1974	382	32.2	65.7	2.1	-	100.0
1975	432	0.5	94.6	4.9	-	100.0
1976	368	12.8	38.6	48.6	-	100.0
1977	434	19.1	72.4	8.0	0.5	100.0
1978	654	5.8	85.0	8.8	0.4	100.0
1979	707	11.0	70.9	17.8	0.3	100.0
1980	678	0.9	94.3	4.9	-	100.0
1981	754	0.4	44.3	55.3	-	100.0
1982	3,419	2.0	61.2	34.4	2.4	100.0
1983	4,110	1.0	53.8	44.4	0.8	100.0
1984	2,722	2.0	73.7	23.9	0.4	100.0
1985	2,472	1.4	68.6	29.2	0.8	100.0
1986	3,473	0.1	29.1	69.8	1.0	100.0
1987	2,184	0.4	60.8	31.8	7.0	100.0
1988	5,112	-	70.1	29.1	0.8	100.0
1989	3,778	0.4	38.7	60.5	0.4	100.0
1990	3,155	0.4	38.3	58.9	2.4	100.0
1991	5,015	1.3	48.0	49.8	0.9	100.0
1992	4,303	0.2	31.0	65.0	3.8	100.0
1993	2,011	0.4	47.5	47.7	4.4	100.0
1994	3,820	0.1	51.3	46.6	2.0	100.0
1995	4,740	0.6	51.9	45.3	2.2	100.0
1996	3,863	0.4	46.2	48.8	4.6	100.0
1997	3,195	0.2	29.0	67.2	3.6	100.0
1998	1,147	0.3	62.8	34.2	2.7	100.0
1999	-	3.9	57.2	37.3	1.6	100.0
2000	-	3.9	57.2	37.3	1.6	100.0
Average	**2,347**	**3.9**	**57.2**	**37.3**	**1.6**	**100.0**
Minimum	**223**	**-**	**29.0**	**2.1**	**-**	**100.0**
Maximum	**5,112**	**32.2**	**94.6**	**69.8**	**7.0**	**100.0**

Data source: Values for the years 1982-1998 from Annual Management Report, Yukon River, 1998 (Bergstrom et al 1999); data taken from page 114. The 1982-1998 data represent weighted averages of the annual age compositions of Yukon chum salmon catches in fisheries throughout the river. Values for the years 1972-1981 from Buklis (1983) and these age compositions are from chum salmon sampled from the Emmonak fishery where they were harvested in 5½-inch gill net mesh. Values used for 1999 and 2000 are average values for the years 1972-1998.

Table 20. Estimated brood table for Andreafsky River summer chum salmon, brood years 1972-1995.

Brood Year	Estimated Escapement	Age-3 Recruits	Age-4 Recruits	Age-5 Recruits	Age-6 Recruits	Estimated Total Recruits	Recruits per Spawner
1972	146,338	8,484	270,053	138,964	5,928	423,429	2.89
1973	187,586	19,563	266,152	96,816	5,485	388,015	2.07
1974	121,515	27,038	228,775	103,067	10,798	369,677	3.04
1975	820,949	9,622	198,894	179,719	7,566	395,800	0.48
1976	399,838	15,721	412,262	155,164	8,499	591,647	1.48
1977	314,204	5,473	190,225	127,466	3,960	327,124	1.04
1978	207,439	2,878	339,864	195,056	2,902	540,700	2.61
1979	196,307	11,101	156,761	41,665	713	210,239	1.07
1980	415,301	2,711	120,666	65,767	6,589	195,732	0.47
1981	290,990	6,199	177,489	183,953	6,867	374,508	1.29
1982	358,230	4,541	233,436	84,341	5,060	327,378	0.91
1983	218,487	971	54,021	53,373	2,524	110,889	0.51
1984	138,520	1,020	140,566	121,835	579	264,000	1.91
1985	212,449	1,952	96,708	20,230	2,395	121,285	0.57
1986	345,179	3,638	97,412	76,961	17,227	195,237	0.57
1987	108,717	1,164	83,135	144,371	3,266	231,936	2.13
1988	150,117	292	55,656	52,843	4,771	113,562	0.76
1989	150,299	69	79,983	128,522	8,828	217,402	1.45
1990	95,249	714	283,907	190,894	13,615	489,130	5.14
1991	140,345	20	168,071	83,918	6,213	258,223	1.84
1992	183,034	2,562	132,116	73,892	2,657	211,227	1.15
1993	122,099	1,137	30,735	22,394	1,724	55,991	0.46
1994	397,004	20	116,991	45,398	1,451	163,861	0.41
1995	340,049	510	19,158	18,830	6,306	44,804	0.13
Average	252,510	5,308	164,710	100,227	5,664	275,908	1.43
Minimum	95,249	20	19,158	18,830	579	44,804	0.13
Maximum	820,949	27,038	412,262	195,056	17,227	591,647	5.14

Table 21. Stock-recruitment relationship statistics estimated for the Andreafsky River summer chum salmon population, brood years 1972-1995.

Stock-Recruit Relationship Statistic	Andreafsky River Summer Chum Salmon Population, Brood Years 1972-1995
Ricker Alpha	2.74085009
Ricker Beta	0.00000271
Adjusted R Square	0.2330
Significance of Relationship	0.0098
Number of Brood Years	24
MSY Escapement Level	161,047
Estimated Maximum Yield	124,418
Estimated MSY Exploitation Rate	44%

Table 22. Residuals in the spawner-recruit relationship developed for the Andreafsky River summer chum salmon population, brood years 1972-1995.

Brood Year	Estimated Escapement	Estimated Recruits	Predicted Recruits	Residual (Estimated Minus Predicted)
1972	146,338	423,429	269,926	153,503
1973	187,586	388,015	309,462	78,552
1974	121,515	369,677	239,715	129,962
1975	820,949	395,800	243,953	151,847
1976	399,838	591,647	371,384	220,263
1977	314,204	327,124	367,959	(40,836)
1978	207,439	540,700	324,313	216,387
1979	196,307	210,239	316,296	(106,057)
1980	415,301	195,732	369,937	(174,205)
1981	290,990	374,508	362,870	11,638
1982	358,230	327,378	372,396	(45,017)
1983	218,487	110,889	331,523	(220,634)
1984	138,520	264,000	260,969	3,031
1985	212,449	121,285	327,673	(206,388)
1986	345,179	195,237	371,729	(176,492)
1987	108,717	231,936	222,025	9,911
1988	150,117	113,562	274,080	(160,518)
1989	150,299	217,402	274,276	(56,875)
1990	95,249	489,130	201,741	287,388
1991	140,345	258,223	263,105	(4,882)
1992	183,034	211,227	305,696	(94,469)
1993	122,099	55,991	240,486	(184,495)
1994	397,004	163,861	371,591	(207,730)
1995	340,049	44,804	371,324	(326,520)

Table 23. Bootstrap estimates of the precision associated with the maximum sustained yield escapement level estimated for the chum salmon population that spawns in the Andreafsky River.

Statistic	Andreafsky River Summer Chum Salmon Brood Years 1972-1995
Mean	167,217
Standard Deviation	74,856
Coefficient of Variation	44%
Lower 90% Confidence Interval	120,381
Upper 90% Confidence Interval	234,726
Indicated Bias	6,170
Indicated Percent Bias	3.7%

Table 24. Years when annual East and West Fork Andreafsky River chum salmon escapements were below, within, or above the biological escapement goal ranges recommended in this report.

| Recommended Biological Escapement Goal Range	Years When Escapement Was Below Recommended Level	Years When Escapement Was Within Recommended Level	Years When Escapement Was Above Recommended Level
East Fork of the Andreafsky River: **65,000 to 130,000 Total Spawners**	1974, 1987, 1990, 1991, 1993, 1997, 1999, and 2000	**1972, 1973, 1978, 1979, 1983, 1984, 1985, 1988, 1989, 1992, 1996, and 1998**	1975, 1976, 1977, 1980, 1981, 1982, 1986, 1994, and 1995
	8 of 29 years 28%	**12 of the 29 years 41%**	9 of the 29 years 31%
35,000 to 70,000 Counted in Aerial Survey	6 years since 1990 54%	**3 of the years since 1990 28%**	2 of the years since 1990 18%
West Fork of the Andreafsky River **65,000 to 130,000 Total Spawners**	1974, 1987, 1990, 1993, 1997, 1999, and 2000	**1972, 1973, 1977, 1978, 1979, 1983, 1984, 1985, 1988, 1989, 1991, 1992, 1996, and 1998**	1975, 1976, 1980, 1981, 1982, 1986, 1994, and 1995
	7 of the 29 years 24%	**14 of the 29 years 48%**	8 of the 29 years 28%
35,000 to 70,000 Counted in Aerial Survey	5 of the years since 1990 46%	**4 of the years since 1990 36%**	2 of the years since 1990 18%
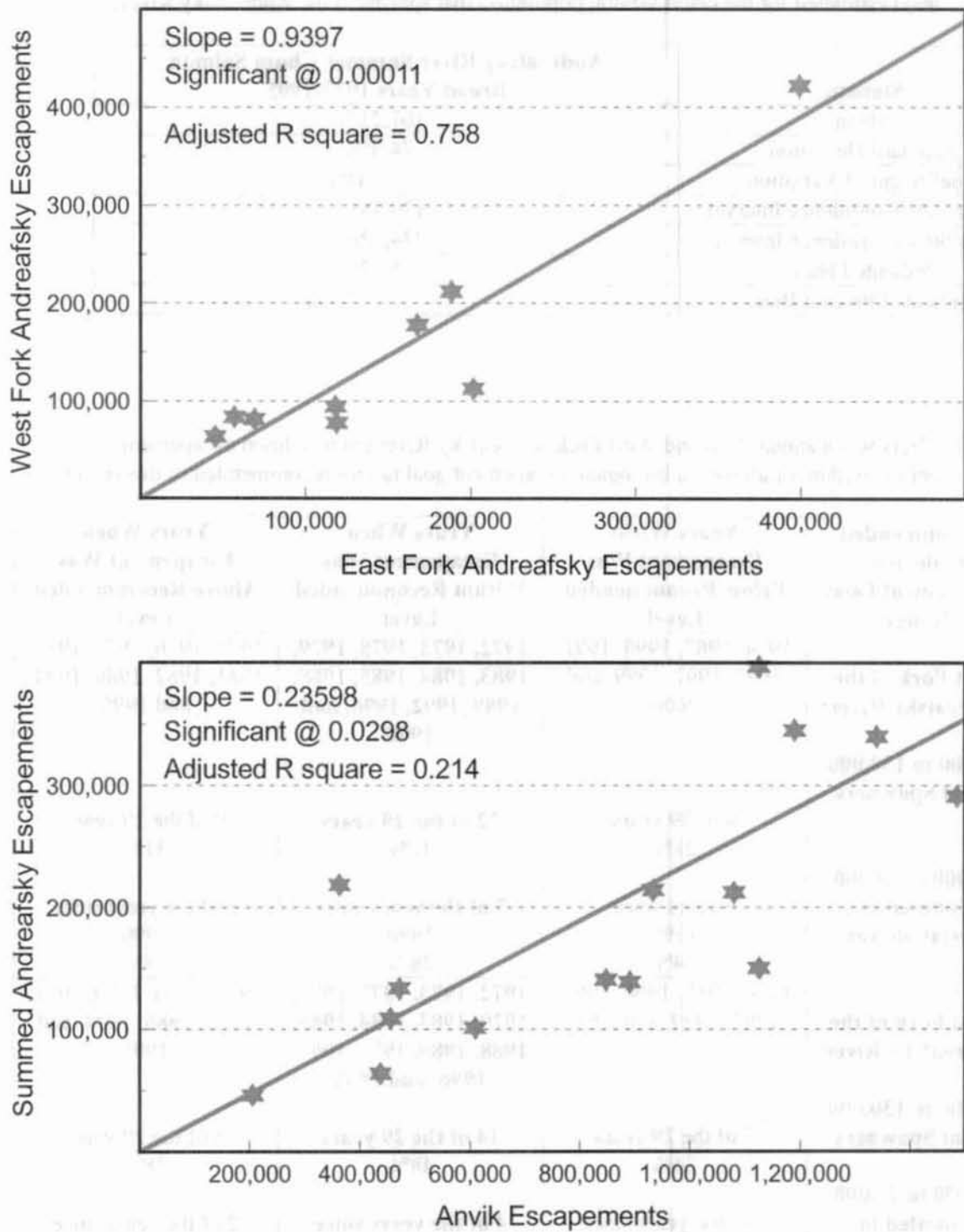
Figure 1. Relationship between East and West Fork Andreafsky River escapements of summer chum salmon (upper panel) and the relationship between the Anvik escapements and the summed Andreafsky escapements of summer chum salmon (lower panel).
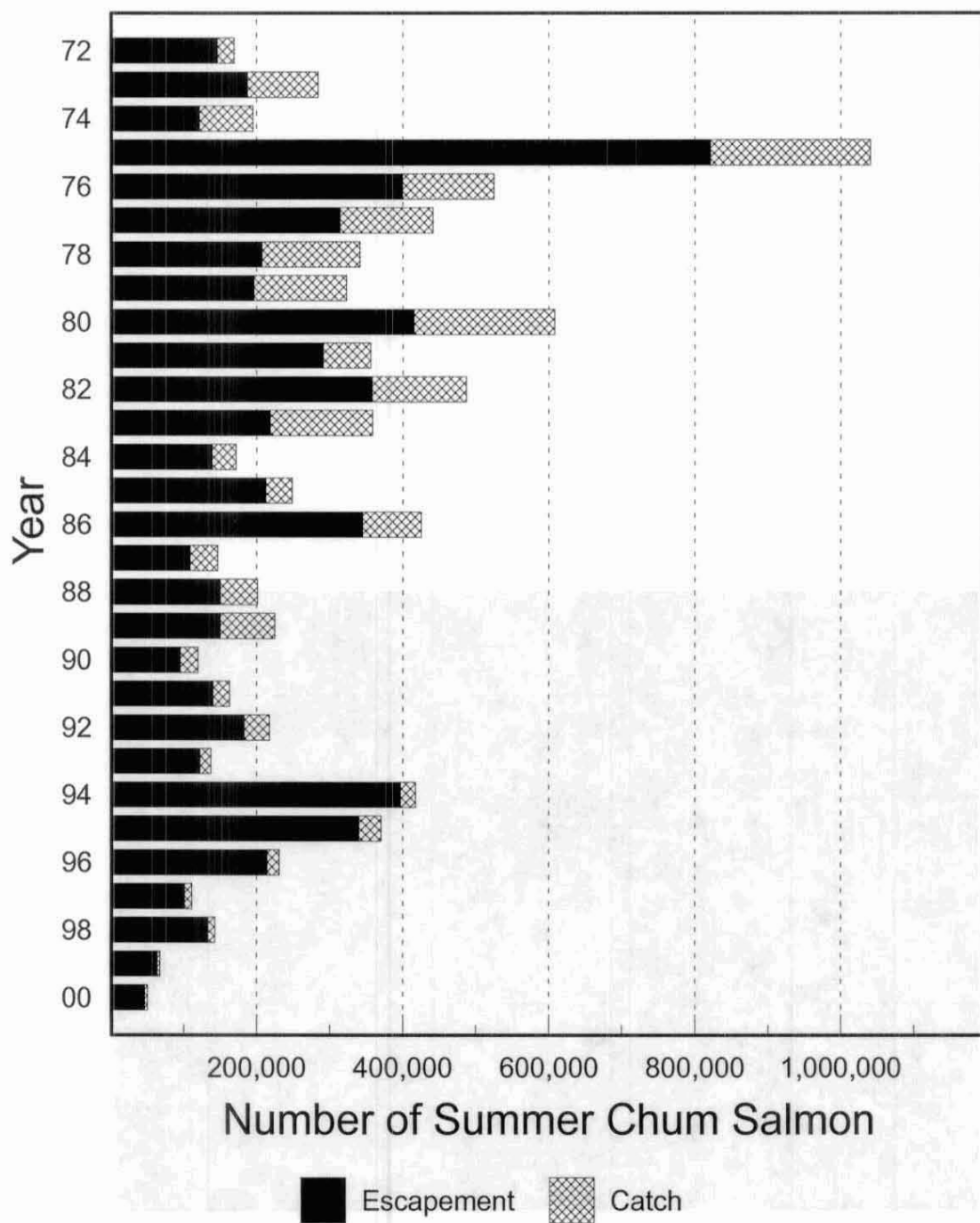
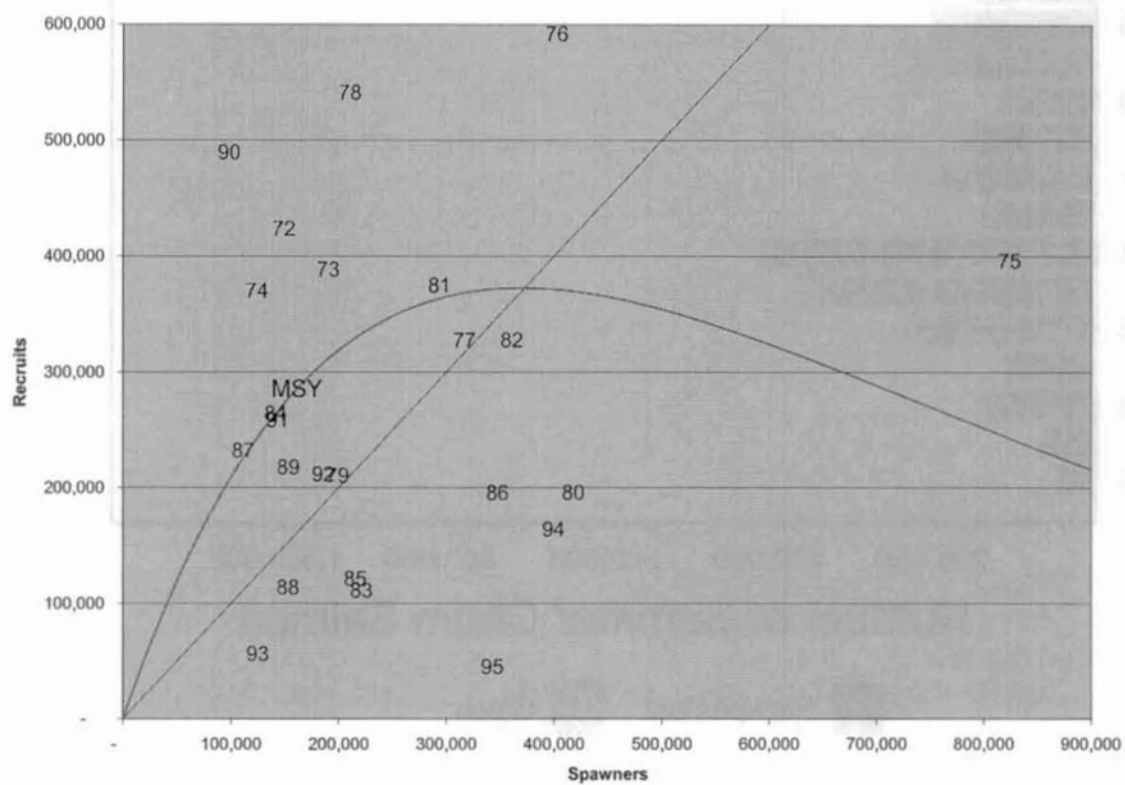Figure 2. Estimated escapements and catches of Andreafsky River summer chum salmon, 1972-2000.

Figure 3. Plot of the spawner-recruit relationship developed for the Andreafsky River summer chum salmon population, brood years 1972-1995.
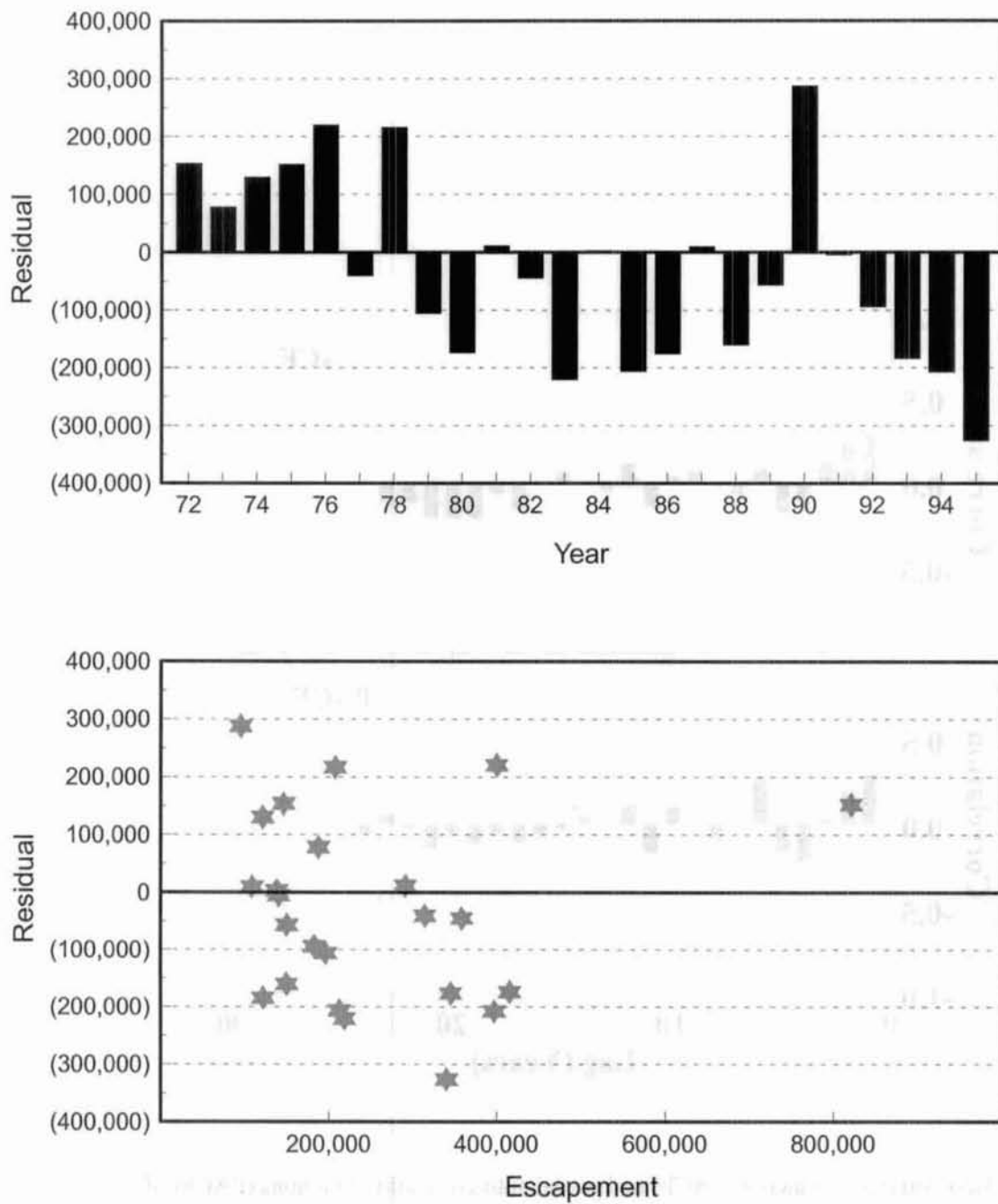
Figure 4. Residuals in the spawner-recruit relationship developed for Andreafsky River summer chum salmon, residuals versus year (upper panel) and residuals versus escapement (lower panel).
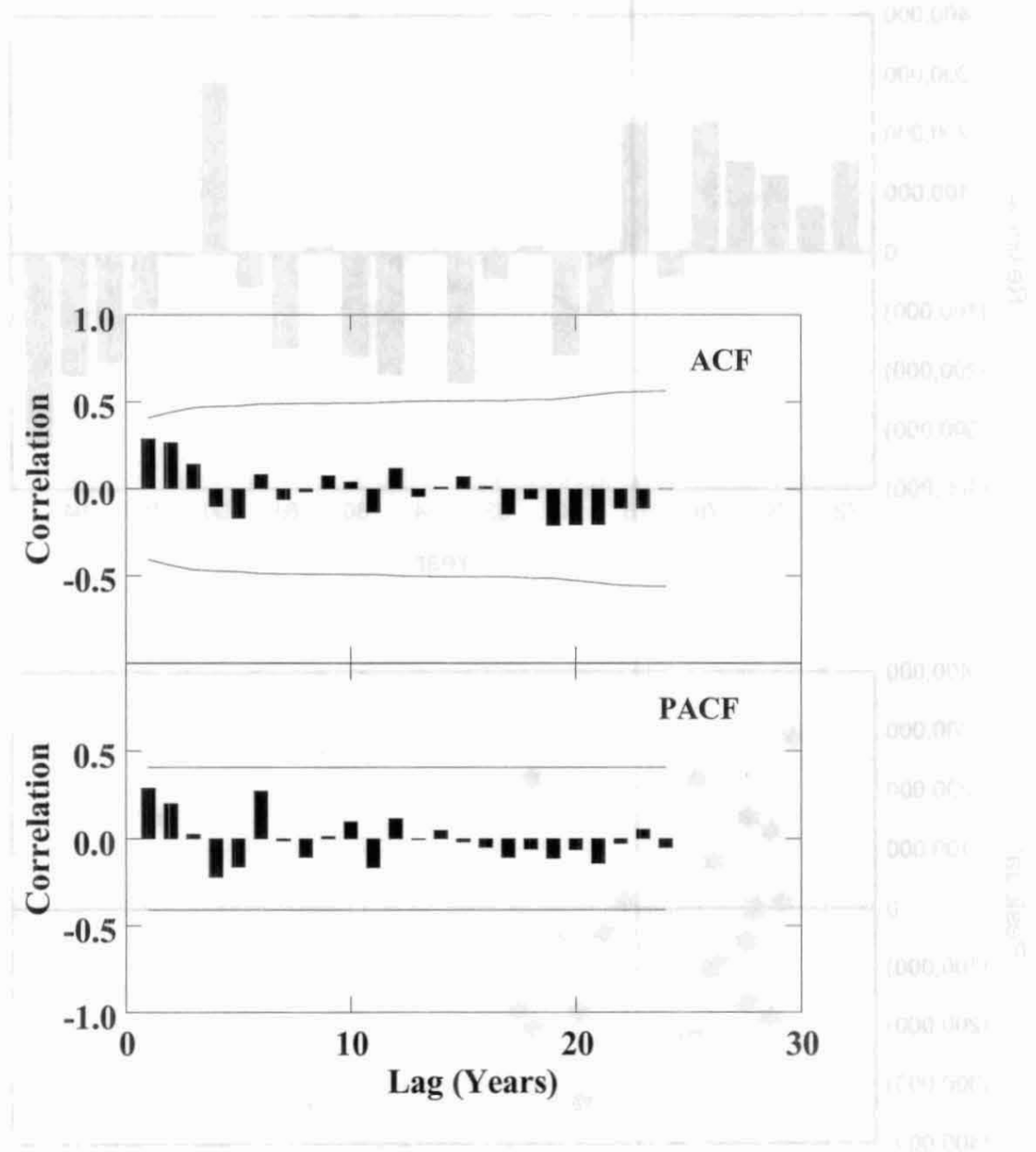
Figure 5. Auto-correlation functions (ACF) and partial auto-correlation functions (PACF) of residuals in the spawner-recruit relationship for Andreafsky River chum salmon, brood years 1972-1995.
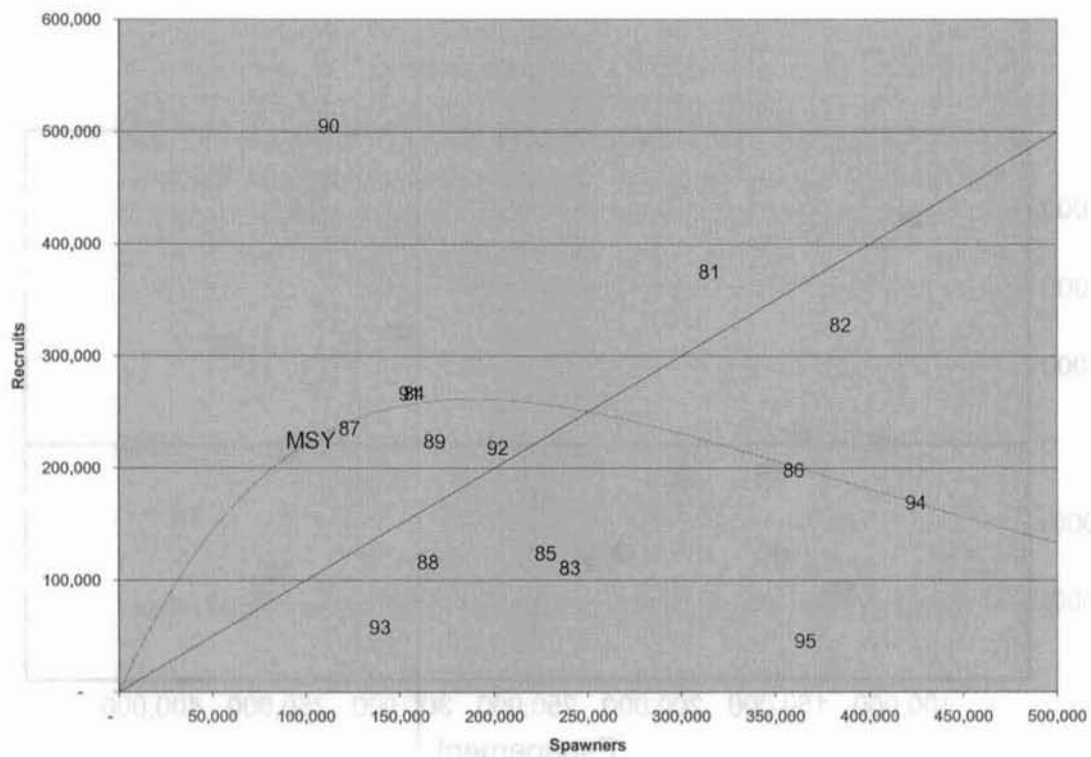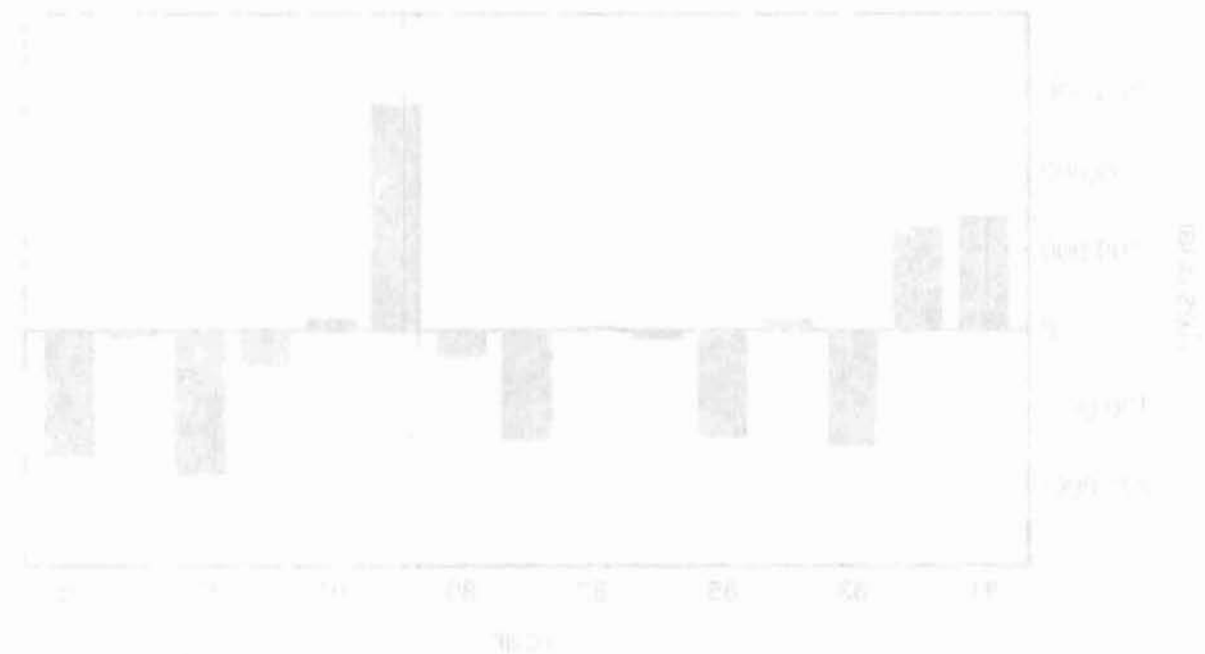
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Figure 6. Plot of the spawner-recruit relationship developed for the Andreafsky summer chum salmon population, brood years 1981-1995.
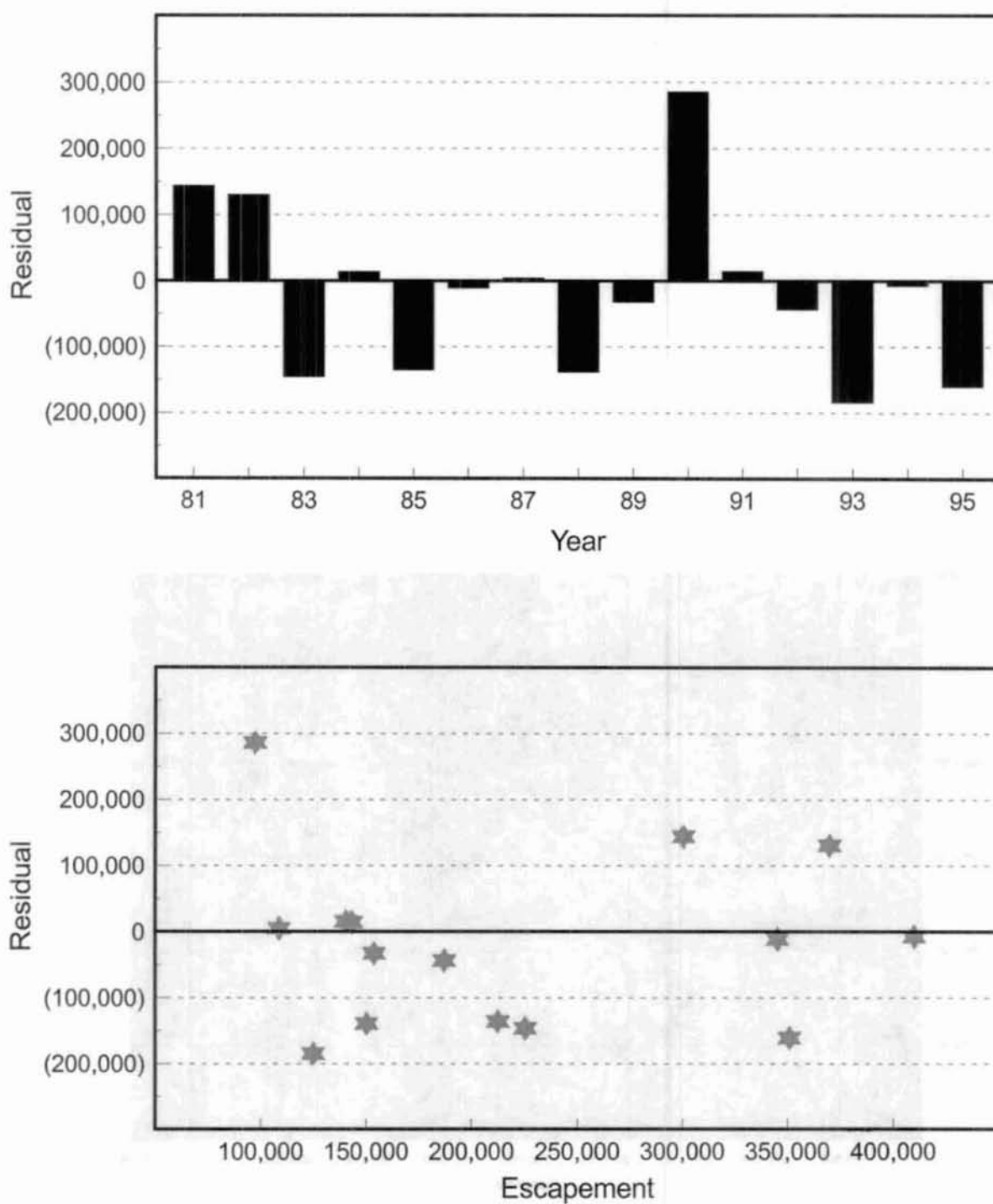
Figure 7. Residuals in the 1981-1995 spawner-recruit relationship developed for Andreafsky River summer chum salmon, residuals versus year (upper panel) and residuals versus escapement (lower panel).